American Journal of Energy Engineering
2014; 2(1): 16-22
Published online February 20, 2014 (http://www.sciencepublishinggroup.com/j/ajee)
doi: 10.11648/j.ajee.20140201.12

Design of cylindrical fixed dome bio digester in the condominium houses for cooking purpose at Dibiza Site, East Gojjam, Ethiopia

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To cite this article:
Molla Asmare. Design of Cylindrical Fixed dome Bio Digester in the Condominium Houses for Cooking Purpose at Dibiza Site, East Gojjam, Ethiopia. *American Journal of Energy Engineering.* Vol. 2, No. 1, 2014, pp. 16-22. doi: 10.11648/j.ajee.20140201.12

Abstract: Organic Waste is undesirable matter, which is most frequently generated by human activity that causes environmental pollution. Therefore, domestic biogas production is one of the most promising method of biomass wastes treatment because it provides a source of energy while simultaneously resolving ecological, environmental and agrochemical issues. The provision of bio - energy tackles both energy poverty and the reliance on polluting and Non - Renewable fuels as a result matured biogas production technology has led to the development of a number of biogas appliances for lighting, power generation, and cooking. The most promising among them is the biogas energy in order to meet the energy requirement for cooking application at domestic and community level. In this paper, an attempt has been made to design and develop a cylindrical torpispherical fixed dome bio digester for cooking application in the condominium houses at Debiza site in Debre Markos, East Gojjam in Amhara Region. The size of biogas plant is $53m^3$ and the input materials are different wastes such as kitchens, food waste and the human excreta from a total of 357 people living in four building of 120 residence. The gas production rating of the developed biogas plant is $25.36m^3$/day, which accounts 60.73% of the energy consumption that covers all the energy demand of firewood, charcoal and animal dung cakes that used for baking Injera and bread. The amount of gas obtained averagely, $0.211m^3$/ per household per day for cooking purpose.

Keywords: Design, Fixed Dome, Biogas, Condominium, Cooking

1. Introduction

Sustainable energy production and its use are important features for adequate energy services for satisfying basic human needs, improving social well-beings, achieving economic development and keeping the quality of life of current and future generations without exceeding the carrying capacity of the ecosystems. However, it has been shown that current energy consumption patterns are aggravating various global problems, leading to further unsustainable. On the other hand, energy can also contribute to the solution of problems particularly poverty, the situation of women, population growth, unplanned urbanization, and excessively consumptive life styles. Thus, poverty alleviation in Developing Countries like Ethiopia should involve in energy strategy of universal access to adequate, affordable, and reliable, high-quality, safe, and environmentally benign modern energy services, especially for cooking, lighting, heating, and transport [1].

In Ethiopia 85-94% of the population is dependent on traditional biomass (firewood, charcoal, agricultural residues, and cow dung) to meet their household energy needs. As reported by the Ethiopian Rural Energy Development and Promotion Center (1998), 77% of total final energy consumption consisted of firewood and charcoal, 15.5% consisted of agricultural residues, roughly, 6% was met by modern energy sources such as petroleum, and only 1% of the population-utilized electricity for cooking. Of the total energy demand, approximately 89% was consumed by households, and 4.6% was to industry. While Ethiopian demand for modern energy sources is expected to grow faster than for any other energy sources, biomass fuels will continue to dominate total energy consumption [2].

Biogas is one of a renewable energy that can be used as an energy resource to substitute firewood in public area such as hotels, hospital, universities, and prisons and new developed in common (condominium) house in this paper. Condominium house is one of the public areas where many people live together in the same room or in different section with the same building in more populated cities or towns of our country. A project was established in Debre Markos Town East Gojjam, Amhara Region in a Kebele 04 (Debiza site). At present, the number of population living in condominium house in Debre Markos is around 3532 in1413 condos house in four different site (Debiza, Bole, Road Construction and Hospital direction) [3]. Where, the energy demand is quite high for heating and cooking purpose.

Although the country has abundant energy resources, its potential is not yet well developed due to lack of financial capital and professional experts. As a result, all the demand of fossil fuel and gas is imported from abroad, and its fuel wood resource are exploited unsustainably which led to deforestation and land degradation. The paramount solution is developing renewable energy sources. During the last years, anaerobic fermentation has developed from a comparatively simple technique of biomass conversion with the main purpose of energy production, treatment of organic wastes, improvement of sanitation, and production of high quality fertilizer. Moreover, it has high economical benefits compared to other fuel sources. Because it requires limited financial capital in construction and maintenance, ease of raw materials availability in villages and towns, has less impact on the environment. Therefore, use of biogas energy has to be prioritized in Ethiopia to reduce deforestation, land degradation, and improve the living condition of the society (i.e. health and socio-economic situation of the households, including gender issues). Furthermore, it reduces the contribution of the green house gasses to climate change and Keeping the quality and sanitation of cities and towns by treating the waste using biogas technology.

Biogas is a potential source of energy, particularly where there is an abundant supply of organic waste. It is expected that, the greatest potential of biogas plant have to be realized through community (institution) and condominiums in large capacities. Therefore, the motivation of Biogas technology should be developed in Ethiopia at condominium house in addition to household level. The survey covered four condominium buildings with 120 residences, which accommodate 357 people. In this condominium house there are a plenty source of human excreta, food and kitchen waste that can produce alternative renewable fuel using a fixed dome bio digester.

This paper focuses on the design of cylindrical fixed dome bio-digester for condominium house in Debre Markos at Debiza site for cooking application from different wastes (food, kitchen, and human excreta). In these building, there are excess dry wastes, human execration as well as food waste. These wastes and human execration have highest hydrocarbon composition, which can be converted to flammable organic component to produce biogas. However, these wastes and human execration have environmental negative impact. Hence, biogas technology when properly utilized improves the sanitary and health conditions of the society and helps the people living there in wide aspects ranging from health to socio-economic improvements.

2. Data Collection and Analysis

2.1. Data Collection

The current number of population in the condominium residence is around 357, as the result of such increment, high amount of kitchen, food wastes and human excreta can be collected. The appropriate amount of waste available and its type should be known before put the design of the digester. Hence, collecting data have been made using interview, questionnaire, direct measurement of the waste using balance for consecutive five month, and different literatures. From this survey, different waste in different state is obtained in the common house of Debiza site in Debre Markos. The solid wastes in the condominiums are two types.

Table 2.1. *Type of solid wastes available and its description in condominiums*

No	Group of was	Description
1	Food waste	Consists of animal ,fruit, vegetable garbage or peel , obtained from preparation or cooking and eating of food including food scrape remaining in each house hold
2	Rubbish waste	Combustible and non combustible waste such as paper, carton ,plastics , wood chips ,broken glass Etc

2.2. Solid Organic Waste

The maximum amount of solid organic waste obtained per month that contains both biodegradable and non-biodegradable from direct measurement using balance recorded as follows for only five month in 2004E.C.

Table 2.2. *Recorded sample of dry waste for five month at Debiza condominiums.*

No.	Month	Amount of waste collected (kg)	Remark
1	October	4943kg	
2	November	4913kg	
3	December	4923kg	
4	January	5400kg	Christmas
5	February	4953kg	
6	Sum	25132kg	
7	Average	5026.4kg	

2.3. Water Source

The water source of the condominiums is tap water, a great care must be taken during shower taking and cleaning (washing) a cloths because the detergent in the waste has negative impact by increasing the pH value. The detergents are basic soaps that are unfavorable for bacterial activity because the water that flows after showering contains detergent mixes with the toilet water in the safety tank. Therefore, it needs little modification to separate them.

2.4. Amount of Waste Obtained from human being

- ✓ Total number of toilets =120
- ✓ Maximum amount of water added to the toilet averagely=2.2L/flash after use, from direct measurement at regular time for one month and taking the average value.
- ✓ The amount of urine discarded per day per person is 1L or 1kg [4] & the amount of manure discarded per day per person is 0.7kg [4, 6].

Data's are obtained from different literature and direct measurement in order to determine the physical properties of the waste obtained from condominiums house are illustrated in the following tables.

One cubic meter of biogas=1ib of LPG=0.454kg, 0.43kg of Butane gas, 1.4kg of Charcoal, 38MJ, 12.30kg of cattle dung cakes, 3.5kg of Firewood [Biswas, 1977]

Table 2.3. *Basic information on the physical properties of the substances*

No.	Type	Quantity
1	Density of food waste	1160kg / m3
2	Density of human waste	1000kg/ m3
3	Water content of food scrape	70%
4	Water content of the human manure	90%
5	Water content of urine	94%
7	Organic content of food waste	85%
8	Mesospheric temperature	25^0c
9	Averagely, solid concentration	8%
10	Retention time	60day
11	Energy content of biogas	38MJ/m^3

Table 2.4. *Energy consumption of household's in condominium house from interview and EEPCO bill price*

No.	Types of fuel	Uses(purpose)	Average Amount per day per household	Amount per Month per household	Total amount of consumed per month per number of residence	Unit price in birr	Cost (in birr)
1	Charcoal	For cooking and heating purpose	0.21kg	6.30kg	100*6.30=630kg	1.68	1061.53
2	Dung cake	For cooking	0.20kg	6kg	6*100=600kg	0.5	300
3	Fire wood	For baking purpose	0.25kg	7.50kg	7.50*100=750kg	1.25	937.5
4	LPG	For cooking stove	0.04kg	1.20kg	1.2*100=120kg	10.45	1254
5	Butane Gas	For cooking stove	0.02 kg	0.60kg	0.6*100=60kg	16.22	973.2
6	Total	-	0.72kg	22.81kg	2218kg	-	5077.83
7	Electricity	For cooking stove only	0.3333kwh	15.76kwh	1576kwh	0.35	551.6

2.5. Energy Cost and Source Related Data

The cost needed to discard the collected waste is 10 birr per month per household or room. The total amount of money spent for this purpose (10*120=1200) per month. Therefore the total amount of cost expense per month is the sum of the two that accounts (1200+5077.83) with a total of 6277.83ETB

2.6. Data Analysis

2.6.1. Waste Obtained from Food and Kitchen

The data obtained from table 2.2 shows, 70% of the wastes are biodegradable and the remaining one is non-biodegradable which accounts 30%. Therefore The total mass of biodegradable solid wastes (peel of potatoes, onion, can sugar, Oaf etc) per month can be calculated as follows:

- ❖ Total mass of biodegradable waste =0.7*5026.4kg/month=3518.2kg/month =117.27kg/day
- ❖ The total mass of non biodegradable waste =0.3x5026.4kg/month=1507.9kg/month=50.26kg/d
- ❖ Daily volumetric flow rate (Sd) in cubic meter per month

$$\text{Sd} = \frac{\text{Total mass of biodegradable wastedkk}}{\text{the density of food waste}} = \frac{3518.2\text{kg/month}}{1160\text{kgm3}} = \frac{3.03\text{m3/month}}{30\text{day/mont}} = 0.101\text{m3}$$

2.6.2. Amount of Human Waste Based on Literature

- ❖ The number of population living in condos=357
- ❖ The amount of manure per day (d) =1kg/day/adult

and 0.4kg / d between 10 to 15 age [5, 6] so considering the average value of the two, it gives = (0.4+1)/2=0.7kg/d. Therefore, the total amount of human waste per day=0.7*357=249.9kg/d.

- ❖ Amount of urine per person per day=1.L/d=0.001 m^3. Therefore, the total amount of urine waste per day=1L*357=357L/d=0.357m^3/d

So, the daily volume flow rate of human waste (Sd)

$$Sd = \frac{\text{total mass of manure waste}}{\text{the density of human waste}} = \frac{\frac{249.9\text{kg}}{\text{d}}}{1000\text{kg/m3}} = 0.249.9m3/d$$

Therefore, Total amount of waste obtained (TW) =Waste obtained from food (WF) + Waste obtained from urine (WU) + Waste obtained from human manure (WM)

$$\text{TW} = (0.101 + 0.357 + 0.249)\text{m3/d} = 0.7079\text{m3/d}$$

Since the waste is wet, applying one to one dilution ratio to achieve the required solid concentration that accounts 8%, so 0.7079m3/d of water is added. Therefore, Volume of the daily charge (Sd) = 1.4158m^3/d

The volume of the digester (slurry) (VD) is defined as the product of the Volume of the daily charge (Sd) and hydraulic retention time (HRT).

The volume of digester = Total waste per day * retention time/ density of waste in one retention time.

VD=Sd*HRT=1.41m^3/d*60d= 85m^3, therefore, the volume of the tank (VD) =43m^3 of two digester to minimize the risk of damaged.

2.7. Balancing Biogas Production and Energy Demand

Determining the Biogas Production: The quantity, quality and type of biomass available for use in the biogas plant are the basic factor of biogas generation. The biogas incidence can be calculated according to different methods applied in parallel.

- ❖ Measuring the biomass availability
- ❖ Determining the biomass supply via pertinent‑literature data
- ❖ Determining biomass supply via user survey

2.7.1. Assumptions Based on Literature

Gas production rate from human waste= 0.078 m^3/kg (1Kg of human excreta produces 0.078m^3 of biogas [4])

Gas production rate from food waste = 0.05 m^3/kg [4]

Retention time =60 days, selected

Ratio of manure and water 1:1dilution

Heat content of methane= 38.13 MJ/m^3

2.7.2. Total Gas Produced

Gas produced from food waste per day =amount of food waste per day*its Gas production rate.

=93.94*0.05=5.8635m^3

Gas from human waste per day = No. of population * human waste per day * its Gas production

=357*0.7*0.078=19.4922m^3

Gas produced from Total waste per day = 5.8635m^3 +19.4922m^3 = 25.3557m^3/d

2.7.3. Determining the Energy Demand

The energy demand of any given farm is equal to the sum of all present and future consumption situations for cooking and heating purpose. Determining biogas demand based on present energy consumption, e.g. for ascertaining the cooking-energy demand. This involves either measuring or inquiring the present rate of energy consumption in the form of wood, charcoal, kerosene and bottled gas. Calculating biogas demand via comparable‑use data: Such data may consist of:

- ❖ Empirical values from neighboring systems,(biogas consumption per person and day)
- ❖ Reference data taken from literature, although this approach involves considerable uncertainty, since cooking energy consumption depends on local cooking and eating habits.

2.7.4. Total Gas Required

The total energy consumption for cooking and heating purpose (Ec) =energy from fire wood +energy from dung cakes + energy from charcoal +energy from LPG+ energy from butane gas+ energy from electricity

$$EC = (750\text{kg} + 150\text{kg} + 540\text{kg} + 120\text{kg} + 60\text{kg} + 1500\text{kwh})/\text{month}$$
$$= (25\text{kg} + 20\text{kg} + 21\text{kg} + 4\text{kg} + 2\text{kg} + 50\text{kwh})/\text{d}$$

One cubic of biogas

=1.4kg of charcoal, implies, 21kg charcoal=1m^3 biogas*21/1.4=15m^3

=0.43kg butane gas, implies, 2kg of butane=1*2/0.43=4.65 m^3

= 0.454kg of LPG implies, 4kg of LPG=1*.4/0.454=8.81m^3

= 3.5kg of fire wood implies25kg of wood=1*25/3.5=7.14m^3

=12.30kg of Cattle dung cake implies 1*20/12.30=1.62m^3

= 38.13MJ, implies= (1*50kwh*3600sec/hr)/38.13MJ=4.72m^3

Therefore, the total energy consumption (EC) = 7.14 + 1.6 + 15 + 8.81 + 4.65 + 4.72) m3/d=41.75m^3/d

The amount of gas produced from organic waste covers 60.73% the energy consumption of the people living in condominiums. If the stove works for a maximum of 3 hours per day, the energy consumption becomes $8.45m^3/hr$ and averagely, 120 house hold obtained $0.0704m^3/h$ gas .The amount of shortage of gas daily equals to total amount of gas consumed daily minus the amount of gas produced daily, EC =41.75-25.36=16.39m^3 /d. Therefore, the total amount of energy demand obtained from firewood, cattle dung cakes and charcoal is nearly substituted by the methane gas produced from different waste material. The remaining energy demand should covered by electricity in order to have free indoor air quality and to contribute in reducing green house gas emission mostly generated from fossil fuel such as carbon dioxide.

3. Design and Sizing of Bio Digester

Among the various types of digesters, in this section of the design, fixed dome torpispherical a continuous feed (displacement) digester is selected for the reason that relatively small amounts of slurry (a mixture of manure and water) are added daily. This enables that gas and fertilizers are produced continuously and predictably. After selecting the type of digester, the retention time, which is a key parameter in determining digester size, is chosen to maximize the percentage of production of biogas with respect to the retention time. Sixty days is chosen as the minimum amount of time for sufficient bacterial action to take place to produce biogas and to destroy many of the toxic pathogens found in human waste.

3.1. Dimension of the Main Parts of the Digester

Dimension of Mixing Pit: The mixing pit of the digester should have a size slightly greater than the daily input and better if no corners.

Assumption: Cylindrical shape is selected based on its advantage as explained on geometrical shape of digester with retention time of 60 day. The diameter (d) and height (h) of mixing pit are equal (d=h)

$V= \pi d^2 h/4$, Where V is the daily substrate flow of the waste after providing 10% safety factor, then the Volume including safety(V)

$V= (10\%*1.41m^3/d)+1.41m^3/d=1.551m^3/d$

In addition, volume can be written in terms of diameter as follows:

$$V=\pi h d^2/4=\pi d^3/4, \text{ solving the diameter (d)}$$

$$d = (4*1.551/3.14)^{1/3}=1.25m$$

Therefore, the mixing height (h) =d=1.25m

Dimension of Compensation Tank: The dimension of the compensation tank (V_{tank}) is around 20% of the volume of the Digester (slurry).

$$V_{tank}=0.20*43m^3=8.6m^3, \text{ for efficient spaces assume cubic shape with length of 'a' then}$$

$$V_{tank} =a*a*a =a^3 \text{ implies } a=\sqrt[3]{Vtank} = \sqrt[3]{8.6} =2.05m$$

3.1.1. Cross Section of a Digester

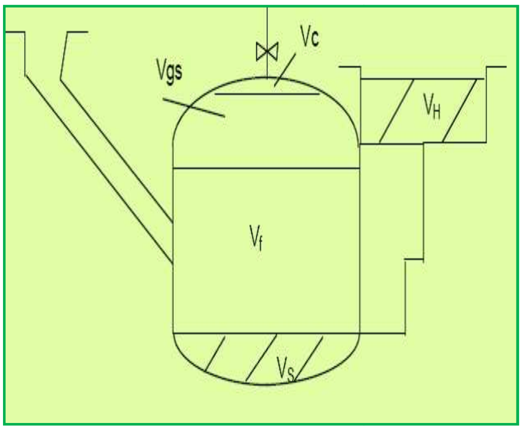

Figure 3.1. *The cross section of digester specifications*

1 Volume of gas collecting chamber at the top layer=Vc
2 Volume of gas storage chamber Vgs, V1=VC+Vgs
3 Volume of fermentation chamber=Vf=V3
4 Volume of sludge layer= V2, Slurry volume V2+V3
5 R1 and R2 is the crown radius of the upper and bottom spherical layer of the digester respectively
6 S1 andS2 art the surface area of the upper and lower dome respectively
7 f1 andf2 are the maximum distance of upper and lower dome

Therefore the total volume of the digester (V) =VC+Vgs+V2+V3=V1+V2+V3, Substituting V1=VC+Vgs

3.1.2. Geometrical Dimensions of the Cylindrical Shaped Biogas Digester

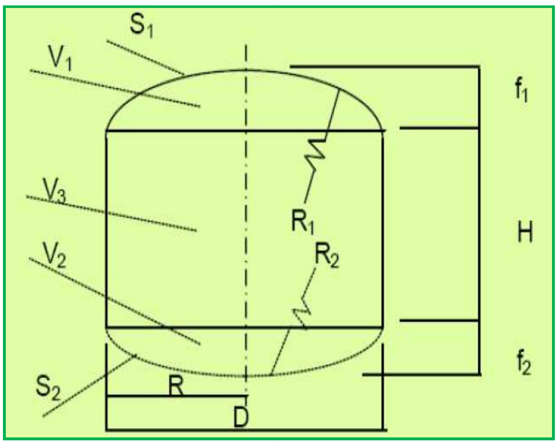

Figure 3.2. *Geometrical dimension of the designed cylindrical fixed dome digester*

For structure stability and efficient performance, fixed dome digester is expressed by the following correlation [7, 8].

For volume	For geometrical dimension
Vp≤5%V	$D=1.3078*V^{1/3}$,f=D/5
V3≤15%	$V1=0.08227D^3$,R1=0.725D, S1=0.911D2
Vgs+Vf=80%V	$V3=0.3142D^3$
Vgs=VH=k(V2+V3)/(1-0.5k),here ,k=0.4m3/m3d ,is gas production rate per m3 digester volume per day	$V2=0.05011D^3$,R2=1.065D,f2=D/8.S2=0.83445D^2, where D is the diameter of digester

3.2. Volume Calculation of Digester Chamber

From the above geometrical dimension correlations: volume of digester (VD) =V3+V2

$=(0.05011+0.3142)D^3=43m^3$

implies $D=\sqrt[3]{\frac{43m3}{0.36431}}$ =4.9m.Therefore the value of each parameter is calculated by substituting the value of diameter in the above geometrical relation presented in table 3.1 and obtained as $V1=9.72m^3$,$V2=5.89m^3$, $V3=36.96m^3$, $VC=2.65m^3$, f1=0.98, f2=0.61m, $S1=21.87m^2$, $S2=20.03m^2$, R1=3.55m, R2=5.21m

Then the total volume (V)

$$V=V1+V2+V3=9.72m+36.96m+5.89m=52.57m^3=53m^3$$

$$Vgs=VH=k\ (V2+V3)/\ (1-0.5k),\ = \frac{0.4(5.89+36.96}{1-0.5*0.4} = 10.71m3\ , V3 = \pi D^2H/4,$$

$$H=4V2/\pi D^2=\frac{4*36.89}{4.9*3.14}=2.01m,\ h = h3/+F1+H1= 159cm$$

(water volume which is fixed or standard)

From assumptions:

VC = 0.05 V = 2.65m3,

Vgs = 10.71m3,

VC + Vgs = 2.65m3 +10.71m3 =13.36m3, the value of V1 again calculated as follows.

V1 = [{(VC + Vgs) - {π *D2 H1}/4] = [13.36 - {3.14 x (4.9) 2x H1}/4] which gives H1 = 0.19m=190mm.The value of the height of the above dome up to the end, have fixed h =159cm water volume (1 mm = 10 N/ m2) h = h3 + F1 + H1 = h3+0.98 +0.19m which gives,

h3 = 0.42m =42cm

Finally, the complete drawing looks like these having all dimensions calculated above or we can take dimensions from standards' having the same plant sizes.

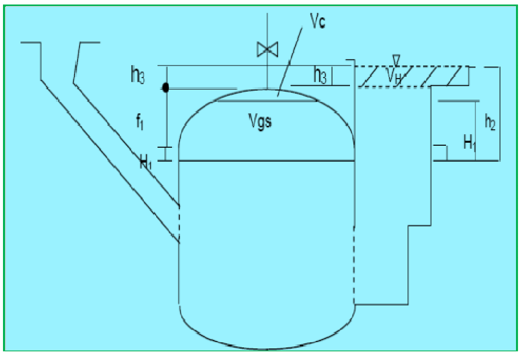

Figure 3.3*. Complete drawing of cylindrical torpispherical fixed dome digester*

Pressure in the Gas Holder or Container: Assume the gas in gasholder obeys ideal gas law i.e. PV=nRT, where n is the mole of gas (n),

$$mole(m) = \frac{\text{mass of the gase(m)}}{\text{molecular mass of gase(M)}}$$

And

$$mass(m) = \frac{\text{density of biogas}(\rho)}{\text{volume of gase(V)}}$$

Substituting all values it gives,

$$P = \frac{\rho RT}{\text{volume of gase(V)}}$$

The value of M=25.8 (65%CH4 and 35%CO_2), universal gas constant(R) =8.314J/mole K, temperature (T) =298K (25^0C) density of biogas (ρ) =1.15Kg/m^3, hence P=1.1bar

Piping: The piping system connects the biogas plant with the gas appliances or users. It should be safe, effectively gas-tight and allow the required gas flow to the appliances during the life span of biogas plant. In this paper, it is recommended to use polyvinyl chloride (PVC) pipe that are economical.

4. Conclusion

The installation of biogas plant leads larger cost saving in addition to environmental and sanitation benefits. The gas produced replaced the total amount of their energy demand that was previous obtained from (charcoal, firewood, and animal dung cake) which accounts 60.73% of their energy needs. The bio-slurry produced after methagonic process also contributes for plantation and garden area present in the condominium house as organic fertilizer. Even thought the initial investment is high to put the plant in to reality, the overall result shows the project is feasible. Therefore taking in to practice the project saves the people living in condominiums from energy cost and from the cost that expense to avoid the collected waste. When the households implement this project, they also play a great role in improving their living standards, environment and creating jobs opportunities for those construct a digester. Therefore investing on biogas is viable option for the production of renewable energies that are important task for our environment.

Acknowledgement

I would like to say thank you to Mr. Simeneh Gedefawu and my best family that give me constant love and help.

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