International Journal of Energy and Environmental Science
2024; 9(1): 1-8
http://www.sciencepublishinggroup.com/j/ijees
doi: 10.11648/ijees.20240901.11
ISSN: 2578-9538 (Print); ISSN: 2578-9546 (Online)

Design of a Cylindrical Fixed Dome Biodigester from Hawassa University Senior Cafe food Waste for Cooking Purposes

Getahun Esubalew Demewoz*, Asnake Helia Tiruneh

Chemical Engineering, Debre Berhan University, Debre Berhan, Ethiopia

Email address:
getahunesubalew80@gmail.com (Getahun Esubalew Demewoz), asnakehelia3@gmail.com (Asnake Helia Tiruneh)

To cite this article:
Getahun Esubalew Demewoz, Asnake Helia Tiruneh. (2024). Design of a Cylindrical Fixed Dome Biodigester from Hawassa University Senior Cafe food Waste for Cooking Purposes. *International Journal of Energy and Environmental Science*, *9*(1), 1-8. https://doi.org/10.11648/ijees.20240901.11

Received: December 16, 2023; **Accepted**: January 3, 2024; **Published**: February 5, 2024

Abstract: Global warming is one of the most dangerous threats that the entire world is facing today. The emission of greenhouse gases is increasing the impact of global warming. In such a situation, reduction of greenhouse gas emissions and finding an alternative source of energy is more and more important. The production of biogas from food wastes is considered a suitable way for the reduction of greenhouse gas emissions. Biogas could provide a more sustainable energy source than wood fuels for rural households in sub-Saharan Africa. Food waste is increasingly becoming a major problem in universities imposing serious environmental impact. Conversion of the food waste using anaerobic digestion (a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen.) to biogas energy is the best option for the management of food waste and for replacement of traditional fuel used (coal) which has been employed for cooking and heating application. In addition, the slurry produced from the process provides digestate which is a source of fertilizer. This paper investigates the potential of food waste left over in the Hawassa University cafeteria to produce biogas.12.75 m^3 per day of biogas from 255 kilograms of food waste per day was produced by 1200 number of students. A fixed dome cylindrical Chinese biogas having a digester volume of 20.3148 cubic meters (m^3) with a retention time of 60 days and the diameter (d) and height (h) of the mixing pit are equal, which is 0.76 meters was required for the biogas production. Anaerobic Digestion is a biological process that takes place naturally when microorganisms break down organic matter in the absence of oxygen. In an enclosed chamber, controlled anaerobic digestion of organic matter produces biogas which is predominantly methane. Besides, food waste is increasingly becoming a major problem in every society imposing serious economic and environmental concerns. For this reason, many contemporary researchers are emphasizing finding sustainable solutions to recycle and produce energy from such waste. In this context, this paper aims to study and optimize the production of biogas from food waste by designing a fixed dome digester.

Keywords: Biogas, Anaerobic Digestion, Fixed Dome Digester, Fertilizer, HRT, Substrate

1. Introduction

Biogas is a mixture of gasses (standard composition: 50-70% CH_4, 30-40% CO_2, 5-10% H_2, 1-2% N_2,0.3% H_2O, and H_2S traces), which is created by a process termed anaerobic digestion, leaving behind a nutrient-rich substance termed digestate [15]. Food wastes are generally biodegradable products that can be generated from the food supply chain (production, processing, packaging, retailing, consumption), and according to FAO, nearly 1.3 billion tons of food are lost in this process [2]. The problems associated with waste disposal are also alleviated by the generation of useful products and decreased release of the potent greenhouse gas, methane, from landfill sites. The process of anaerobic digestion that alters organic matter into biogas flourishing in methane in the penury of oxygen consists of four phases [23].

The first phase, Hydrolysis, converts complex organic compounds to simple soluble compounds by hydrolytic microorganisms. The second phase, acidogenesis: converts soluble organic compounds into VFA (Volatile Fatty Acid) and CO_2 through acidogenic bacteria. Then, in the acetogenesis phase, Volatile Fatty Acids get oxidized into the methanogenic substrate, and finally, in the methanogenesis phase acetate, carbon dioxide, and hydrogen are transformed into methane gas by methanogenic bacteria which are immensely sensorial to ambivalent circumstances for their sustainable growth [17].

Controlled environmental conditions (pH, alkalinity, temperature, toxicity) are essential for anaerobes to function their metabolic activity efficiently. The success of methanogenic bacteria will mainly depend on seeding, temperature, pH, carbon-nitrogen (C/N) ratio, volatile fatty acids (VFAs), organic loading rate (OLR), alkalinity, total volatile solids (VS), and hydraulic retention time (HRT) and nutrients concentration [2]. Biogas production from such sources offers alternative fuel, biofertilizer, electricity, waste recycling, greenhouse gas emission reduction, and environmental protection [25].

Biogas technology is an integrated waste management system that is a clean, renewable, naturally produced, and underutilized source of energy. It is produced in an air-tight tank from a variety of substrates, such as animal manure, food waste, energy crops, and industrial wastes [24]. A biogas digester is also known as a methane digester. It is a piece of equipment that can turn organic waste into usable fuel. These devices are sometimes known as anaerobic digesters. One of the major applications of biogas digester is in the disposal of human and farm waste [18]. The main aim of this research work was to design and test a Biogas digester that is cheap, easy to operate, and easy to assemble. Also, it provides a means of obtaining fuel for cooking at a cheap rate.

Problem Statement

Energy is a fundamental input in the development of any human society. However, the amount of energy required per capital to foster or sustain development depends largely on the state of development, the local resources, the social and economic model chosen by the country, and other factors. Today most countries rely on local or imported nature, coupled together with the environmental effect of fossil fuels have remarkably influenced the development of energy sources. Ethiopia is exposed to international price volatility that affects its balance of payment due to its dependence on fossil fuel imports.

Furthermore, our country is facing a big problem with the accumulation of food waste released from cafeterias and other sectors. Especially, there is a huge accumulation of food waste in Ethiopian universities. There is a huge discharge of food waste as the university contains many students who consume their food in the provided cafeteria. The food leftover in the cafeteria is causing major environmental and health problems, starting from the bad smell that influences the health of human beings to the serious environmental problem caused by the release of greenhouse gases.

The electricity problem exists in Ethiopia both in rural and urban areas is the main challenge in the day-to-day income of the society, which utilizes electricity for their work. The best option to alleviate this problem could be to find a sustainable remedy such as transforming all that food waste to energy biogas. This option not only minimizes the problem associated with food waste accumulation in the university but also it is an alternative source of energy that could be used for many applications such as heating, cooking, and lighting.

2. Literature Review

Biogas is produced by an anaerobic digestion (AD) process whose benefits include the production of a renewable energy resource while the process can lead to the treatment of feedstock during the treatment and also produce digestate which is a useful organic fertilizer that can substitute chemical fertilizers in sustainable agriculture [13]. Biogas is produced by the anaerobic action of a class of bacteria under suitable conditions. Gas is an environmentally tally friendly energy resource with a calorific value between 21 and 24MJ/m^3 [8].

The anaerobic digestion process can be subdivided into four main processes, the first process is comprised of two extracellular stages which include disintegration and hydrolysis, in which sugar, amino acids, long-chain fatty acids, and other associated compounds are collected by the breakdown and solubilization of complex organic matter such as carbohydrates, proteins, and fats. Usually, hydrolysis is considered the slowest step in the overall process and is regarded as the rate-limiting step in the degradation of organic matter [4].

The second part of the process includes three intracellular stages: acidogenesis or fermentation, the next step after hydrolysis, in which hydrogen (H_2) and carbon dioxide (CO_2) are produced, and the final stage which converts long-chain fatty acids (LCFAs) into volatile acids (VFAs) such as acetic acid, propionic and butyric by acidogenic bacteria. In the acetogenesis phase, acetate is produced by the transformation of VFAs by acetogenic bacteria into hydrogen and carbon dioxide. In the final phase, methanogenesis, methane is produced through two major metabolism pathways: acetate decomposition and hydrogenotrophic methanogenesis, by using the intermediate products (H_2 and CO_2) [8].

2.1. Factors Affect Anaerobic Digestion

Temperature

One of the most critical parameters influencing the performance of any anaerobic digestion process is temperature. Methanogenic bacteria and volatile acid-forming bacteria are affected by temperature, and the enzyme activity that is secreted by these bacteria changes according to the temperature. Thereby, it influences methane formation. There are three temperature operating conditions for the anaerobic digestion process: psychrophilic (~ 20°C), mesophilic (~ 35°C), and thermophilic (~ 55°C) [23].

pH

pH is an essential parameter that impacts the process's efficiency, indicating and controlling its stability. In addition, microorganisms are extremely sensitive to pH because different bacteria communities require various pH ranges. Maximum methane production was achieved at a pH of 7, while an 88% reduction of methanogen production was observed at pH 5.5 in continuous anaerobic digestion of waste-activated sludge [8].

Carbon to Nitrogen Ratio

C/N As a critical ratio that can appreciably affect the anaerobic digestion activity, the carbon to nitrogen ratio (C/N) was established as a feedstock character. Several studies have found that an ideal C/N ratio of 20–30 results in an efficient AD process [10].

Organic Loading Rate (OLR)

OLR can typically be determined as a kilogram of the volatile solid (VS) loaded per volume of digester per day and can even be adjusted and regulated to maintain the stability of the AD process [4].

Total Solids Content (TS %)

Generally, the AD process is divided into three ranges based on TS (total solid) percentages, i.e., wet (≤ 10%), semi-dry (10–20%), and dry (≥ 20%) [23].

Volatile Fatty Acid (VFA)

Inhibition In the hydrolysis step, short-chain fatty acids are produced as a result of biodegradable, more complex organic matter such as long-chain fatty acids (LCFAs) and other soluble compounds. They are popularly known in the literature as volatile fatty acids (VFAs). The main types of VFAs widely found in the hydrolysis stage are acetic, propionic, butyric, and valeric acid [4].

Ammonia Inhibition

Nitrogen as a by-product of proteins is considered the main source for microbial growth. Furthermore, the distribution of nitrogen is necessary for the anaerobic digestion process because a high concentration of ammonia nitrogen leads to anaerobic digestion process inhibition [10].

2.2. Co-Digestion, Pretreatment Methods, and Mixing Techniques Effect on the Anaerobic Digestion Process

Effect of Co-Digestion

Typically, anaerobic co-digestion is defined as a strategy of mixing two or more substrates for simultaneous processing. This technique has been applied to overcome the potential limitations and problems of the mono-digestion process, such as system instability due to inhibitory factors, low methane yield caused by mono substrate characteristics (a notable example is FW, known for high carbon content, low alkalinity, high organic loads, and low nitrogen content [3].

Effect of Pretreatment Techniques

The anaerobic digestion process has critical drawbacks due to its complexity and inhibitory factors. Among the adequate solutions that improve the process by increasing the rate of decomposition of the organic fraction and the generation of methane, otherwise improving process efficiency, is the application of pretreatment methods [25].

Effect of Mixing Methods

Mixing is one of the methods that can influence anaerobic digestion efficiency because it keeps microbes in contact with the substrate, promotes uniform conditions throughout the digester volume, and improves process kinetics and methane production [15].

3. Materials and Methods

3.1. Materials

The main equipment used in the study was food waste, water, Weighing balance, Waste collector, pH meter, Measuring Cylinder, Mixing Tank, and Water tank. The main building materials for the biogas digester are bricks, sand, concrete stones, and Portland cement.

3.2. Methods

3.2.1. Data Collection

The total number of students in the Hawassa University senior cafe is 1200, and as a result of such increment, a high amount of food waste can be collected. The appropriate amount of waste available and its type should be known before the design of the digester. Hence, collecting data was made using interviews, questionnaires, for consecutive seven days, and different kinds of literature. From this, we have the following tabulated food solid wastes in the senior café.

Table 1. *Recorded sample of food waste in a week from senior café.*

	Food waste (in quintal)			Remark	
Days	Breakfast	Launch	Dinner	Total	
Sun day	-	1.5	1.5	3	
Tuesday	-	1	2	3	Shiro at dinner
Wednesday	-	1.5	1	2.5	
Thursday	-	1	2	3	Shiro at dinner
Friday	-	1.5	1	2.5	
Saturday	-	1	2	3	Shiro at dinner
Monday	-	2	2	4	Shiro at launch, watching football
Total	-	9.5	11.5	21	

Adding the above food waste we have 21 quintal (21,000 kg) of food waste for seven days.

3.2.2. Water Source

Water is often the key factor limiting the implementation of biogas; a survey conducted in Ethiopia showed that of 700 biogas digesters, 60% were non-operational due to lack of water or manure. It is suggested that to run a biogas digester efficiently, the time taken to reach the water source should be no more than 30 min [22]. There are Methods to meet water demand, these are Recycling domestic water, Rainwater harvesting, and Aquaculture [21].

3.2.3. Data Analysis

The maximum amount of solid organic waste obtained per week that contains both biodegradable and non-biodegradable from taking the following assumption:

Table 2. *Basic information and assumption biogas calculation.*

No	Type	Quantity	References
1	Density of food waste	1160 kg/ m^3	(Wong, 2021)
2	Mass of biodegradable waste	70-80% Total collected food waste	(Van, 2020)
3	Mass of non-biodegradable waste	20-30% Total collected food waste	(Paladino, 2022)s
4	Gas production rate	0.05 m^3/kg	(Wang, Hu, Wang, Wu, & Zhan, 2023)
5	Dilution ratio	1:1	(Dong, Chen, Li, & Zhang, 2018)

Now using the above assumptions, we have that: 21 quintal food waste $\times$ 85 kilo garam/1 kuntal =1785 kilogram of food waste/weeks. Now we have 1200 students in the senior cafe, so that to know the amount of food waste for each person, we have

1785 food waste/1200 students=1.4875 kilograms of food waste per week

Now to know the amount of waste per day we have to multiply by the number of days in a week. Amount of food waste per day= ((1785 kilogram of food waste/weeks)) / (7 days/week)=255 kilograms of food waste per day. Now we have that 255 kilogram of food waste per day, and we can calculate:

1. Mass of biodegradable waste= 0.7 $\times$255 kilogram of food waste per day =178.5 kilogram per day
2. Mass of Total mass of non-biodegradable waste=0.3 $\times$255 kilogram of food waste per day=76.5 kilogram per day

The substrate input depends on how much water has to be added to the substrate in order to arrive at a solids content of 4-8%. Here Substrate input (Sd) = biomass (B) + water (W)

1. Mass of biomass (biodegradable waste)= 178.5 kilogram per day
2. Mass of water =178.5 kilogram per day (from Dilution ratio =1:1)

The daily amount of input material (Sd) is the sum of the residual and the dilution of the biomass (residual and water) (La et al., 2021). Now the total substrate input (total slurry) = mass of water + Mass of biomass (biodegradable waste) = 178.5 kilogram per day+178.5 kilogram per day =357 kilogram per day. Daily volumetric flow rate (Total mass of biodegradable slurry waste)(density of food waste)

Daily volumetric flow rate =(357 kilograms per day) / (1160 killo gram / cubic meter) . Then the Daily volumetric flow rate =0.3078 (cubic mater) / (day)

3.3. Total Gas Produced

Assuming that taking gas production rate from food waste is 0.05 (cubic meter) / (kilogram) [24]. Total Gas Produced from food waste per day =amount of food waste per day$\times$ its Gas production rate. Total Gas Produced from food waste per day =255 kilograms of food waste per day $\times$0.05 cubic meters per kilogram. Total Gas Produced from food waste per day =12.75 cubic meters per day

Here from the senior café that has 1200 students, we collected 255 kilograms of food waste per day, and from this waste, we will produce 12.75 cubic meters per day of biogas. This is a high amount of energy to use for different purposes.

3.4. Design and Sizing of Bio Digester

The biogas plant has two main parts: these are the digester/digester chamber where the biogas fermentation of the organic matter occurs and the gas holder/gas storage chamber where the biogas is collected and stored. Among the various types of digesters, in this section of the design, fixed dome cylindrical Chinese biogas a continuous feed (displacement) digester is selected for the reason that relatively small amounts of slurry (a mixture of food and water) are added daily [19]. This enables gas and fertilizers to be produced continuously and predictably [9].

3.4.1. Sizing the Digester

Digester volume is determined on the basis of the chosen retention time and daily substrate input quantity. The retention time, in turn, is determined by the digesting temperature. The hydraulic retention time (HRT) is the average time during which the feedstock remains in the biogas digester [6].

Practical experience shows that retention times is 40-100 days. For a night soil biogas digester, a longer retention time (70-80 days) is needed so that the pathogens present in human feces are destroyed. Extra-long retention times can increase the gas yield by as much as 40 %. For a stable anaerobic digestion (AD) process influencing both physicochemical parameters and microbiota. Digesters are commonly operated at 35 to 39°C or 50 to 55°C in the mesophilic or thermophilic operation modes, respectively [23]. Since Hawassa is found in hot tropical regions and to ensure complete degradation of slurry, the retention time of 60 days is assumed. The size of the digester, i.e. the digester volume (VD), is determined on the basis of the chosen retention time (RT) and the daily substrate input quantity (SD) [27].

Assumptions:

Retention time (RT)=60 days as the minimum amount of time, selected, this is due to [31].:

1. For sufficient bacterial action to take place to produce biogas and
2. To destroy many of the toxic pathogens found in human waste

Using a safety factor of 10% [5].

Now we have to calculate the size of the digester, using the collected data and the above assumptions.

VD (m^3) = SD (m^3/day) $\times$ RT (number of days)

VD= SD × RT

VD=0.3078 $(cubic\ mater) / (day)$ ×60 days

VD= 18.468 cubic meters (m³)

Now using the assumption of a safety factor of 10%

VD= 18.468 cubic meter (m³) +18.468 cubic meter (m³)×10%

VD=20.3148 cubic meters (m³)

N. B: Here to produce 12.75 cubic meters per day of biogas from 255 kilograms of food waste per day, we have to design a fixed dome cylindrical Chinese biogas having a digester volume of 20.3148 cubic meters (m³).

3.4.2. Dimension of the Main Parts of the Digester

Dimension of Mixing Pit: should have a size slightly greater than the daily input and better if no corners. Assuming that a cylindrical shape is selected based on its advantage as explained on the geometrical shape of the digester with a retention time of 60 days and the diameter (d) and height (h) of the mixing pit are equal, h/d=1 [30].

since a Cylindrical shape is selected

V=(π × d × d × h) / 4, we have that, h= d, Then

$$V= \pi \times d \times d \times h/_4, (h=d)$$

$$V=(\pi \times d \times d \times d) / 4$$

From the above section, we have the daily substrate flow after providing a 10% safety factor.

V=0.3$(cubic\ mater) / (day) + 0.3078 (cubic\ mater) / (day) \times 10\%$

V=0.34 $cubic\ mater) / (day)$

diameter of the mixing pit (d)

Now to determine the diameter of the mixing pit (d) we have to substitute the value of digester volume (VD) into equation (4), We have that

$$V=(\pi \times d \times d \times d) / 4$$

$$0.34\ cubic\ mater) / (day)=(\pi \times d \times d \times d) / 4$$

$$d=\sqrt[3]{((4 \times V)/\pi)},\ d=\sqrt[3]{((4 \times 0.34)/\pi)},\ d=\sqrt[3]{25.8787}\ m$$

d=0.76 meter

height of mixing pit (h)

To find the height of the mixing pit we have to substitute the value of d that is from the above into equation (h/d=1), h= d, then h= 0.76m

3.4.3. Cross Section of a Digester

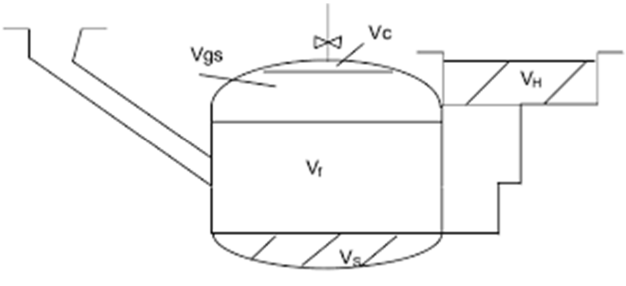

Figure 1. *The cross section of digester specifications.*

Where:

1. Volume of gas collecting chamber at the top layer=Vc
2. Volume of gas storage chamber Vgs,
3. Volume of fermentation chamber=Vf
4. Volume of sludge layer= Vs
5. Hydraulic chamber =VH

Total volume of digester V =Vc+Vgs+Vf+Vs

3.4.4. Geometrical Dimension of the Cylindrical Shaped Biogas Digester

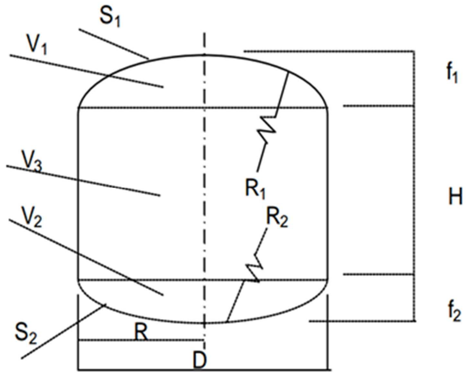

Figure 2. *Geometrical dimension of the designed cylindrical fixed dome digester.*

Where

1. S_1 and S_2 art the surface area of the upper and lower dome respectively
2. f_1 and f_2 are the maximum distance of upper and lower dome
3. R_1 and R_2 is the crown radius of the upper and bottom spherical layer of the digester respectively
4. V_1=VC+Vgs
5. V_2= Vs
6. V_3=Vf

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

Table 3. *Assumptions of Volume and Geometrical dimensions.*

Volume	Geometrical dimensions
Vc≤5% V	D=1.3078 * V1/3
Vs ≤ 15% V	V1=0.0827* D3
Vgs + VF = 80% V	V2 = 0.05011 *D3
Vgs = VH	V3 = 0.3142 *D3
Vgs = 0.5 (Vgs + VF + Vs) K	R1= 0.725 *D
Where K = Gas production rate per m3	R2= 1.0625 *D
Digester volume per day. K= 0.4	f1 = D/5
	f2 = D/8
	S1 = 0.911 D2 & S2 = 0.8345 D2

3.4.5. Volume Calculation of Digester and Hydraulic Chamber

(i). Volume Calculation of Digester Chamber

From the above geometrical dimension correlations and from Figure 2 we have that the volume of digester (VD) =V_3+V_2= (0.05011+0.3142) ×D^3.

But the volume of the digester (VD from SD × RT) =20.3148 cubic meters (m³) by using a 10% safety factor.

Now 20.3148 cubic meter (m³) = $(0.05011+0.3142) \times D^3$

20.3148 cubic meter (m³) = $0.36431 \times D^3$

D^3=(20.3148 cubic meter (m^3)) / 0.36431=55.76 m³)

$$D=\sqrt[3]{55.76\ m^3}$$

D=3.82 meter

Here we have the relation between the height and the diameter of the digester for Chinese biogas digester, that is:

$$h/D=1/3$$

Now the height of the digester becomes

$$h=D/3 = 3.82\ meter/3=1.27\ m$$

Therefore the value of each parameter is calculated by substituting the value of diameter in the above geometrical relation presented in Table 3 and obtained as

1. Finding the distance from the ring beam to the manhole (f_1) $f_1= D/5= (3.82m)/5=0.764$ m
2. Finding the distance from the bottom center to the wall bottom (f_2) $f_2= D/8= 3.82m/8=0.4775$ m
3. R_1 and R_1 are the crown radii of the upper and bottom spherical layers of the digester respectively. Then $R_1 = 0.725\times D= 0.725\times 3.82\ m=2.7695$ m and $R_2 = 1.0625\times D=1.0625\times 3.82\ m=4.058$ m
4. Volume of gasholder chamber (V_1), $V_1=0.0827\times D3=0.0827\times (3.82\ m)\ 3$, $V_1=4.609\ m^3$
5. Volume of sludge chamber (V_2), $V_2=0.0511\times D3=0.0511\times(3.82\ m)\ 3$, $V_2=2.848\ m^3$
6. Volume of fermentation chamber (V3), $V3=0.3142\times D3=0.3142\times(3.82\ m)\ 3$, $V3=17.514\ m^3$
7. Total volume of digester (VT), $VT=V1+V2+V3=4.609\ m^3+2.848\ m^3+17.514\ m^3$, $VT=24.97\ m^3$
8. Volume of gas collecting chamber (Vc), $VC=15\%VT=0.15\times 24.97\ m^3$, $VC=3.7455\ m^3$
9. Volume of gas storage chamber (Vgs) $Vgs=VH= (k\ (V2 + V3)) / ((1 - 0.5k))$ $Vgs= VH= (0.4\ (2.848\ m3 + 17.514\ m3)) / ((1 - 0.5 * 0.4))$ $Vgs= 10.18\ m^3$
10. Volume of slurry (Vs), Vs= V2+ V3 $Vs=2.848\ m^3+17.514\ m^3=20.362\ m^3$ or We can calculate by using the following correlation $Vs=85\%VT=0.85\times 24.97\ m^3=21.2245\ m^3$

Here to calculate volume of slurry (Vs), by using the two methods, almost they are approximately equal, that means volume of slurry (Vs) from total volume digester, $21.2245\ m^3\approx 20.362\ m^3$ volume of slurry (Vs) from the sum of volume of fermentation chamber (V_3) and volume of sludge chamber (V2).

11. S_1 and S_2 art the surface area of the upper and lower dome respectively
12. $S_1=0.911\times D2=0.911\times (3.82m)2=13.29\ m^2$
13. $S_2=0.8345\times D2=0.8345\times (3.82m)2=12.17\ m^2$

(ii). Volume Calculation of Hydraulic Chamber

The value of V1 again calculated as follows. $V1 = [(VC + Vgs) - \{\pi \times D^2 \times H1\}/4]$

$$V1= [\{3.7455\ m^3+10.18\ m^3-\{\pi \times (3.82m)^2\times H1\}]/4$$

$$4.609\ m^3= [3.7455\ m^3+10.18\ m^3-\{\pi \times (3.82m)^2\times H1\}]/4$$

$$-9.3165=-(45.84H1)/4$$

$$H1=0.812\ m$$

The value of the height of the above dome up to the end, have fixed h =159cm water volume (1 mm = 10 N/ m2)

$$h = h3 + f1 + H1$$

From the above we have that. H1=0.812 m=81.2 cm

$$h = h3 + f1 + H1$$

$$159\ cm=h3 + 0.764\ m+0.812\ m$$

$$H3=1.4\ cm=0.014\ m$$

3.5. Operating Parameters of Dry Anaerobic Digestion

Table 4. *Operating parameters of dry anaerobic digestion.*

No	Type	Quantity	References
1	Temperature	Psychrophilic, 5-25°C, (optimum temp = 10°C) Mesophilic, 25 – 38°C, (optimum temp = 35°C) Thermophilic, 50 –70°C, (optimum temp = 55°C)	(Agori, Nwoke, & Dike, 2021)
2	pH	6.5 - 7.5	(Hossain & Hasan, 2018)
3	Total solid	7-9%	(Waqas, Almeelbi, & Nizami, 2018)
4	Hydraulic retention time	70-80 days	(Wong, 2021)
5	Carbon/nitrogen ratio	20:1 to 30:1	(Mukumba, Makaka, & Mamphweli, 2019)

4. Results and Discussion

4.1. Physiochemical Characteristics of Food Waste

Table 5. *Result of physiochemical characteristics of food waste.*

No	Parameters	Unit
1	moisture content	82± 2.1%
2	TS (%)	11± 1.5%
3	volatile solids	85 ± 5%
4	pH	5.1 ± 0.7
5	The carbon-to-nitrogen (C: N)	28±1.2

From the above table, the total solid, which is the amount of solid parts present in the sample food waste, was 40 of 100 grams. This means that 60% of the sample food waste is water or moisture. The volatile solid, which is the amount of organic content of the food waste was 85 ± 5%and this organic content is useful to generate biogas after anaerobic bacteria utilize it.

4.2. Biogas Production from Hawassa University Food Wastes

Projects with food waste showed that after digestion at retention times of 40 days. Also, the methane production was higher in the two-stage reactor than in the single one when the gas production was normalized to the feedstock input. Therefore, the fermentation stage serves as an equalization buffer in the event of shock loading, providing safety for the anaerobic digester system. To produce 12.75 cubic meters per day of biogas from 255 kilograms of food waste per day, we have to design a fixed dome cylindrical Chinese biogas having a digester volume of 20.3148 cubic meters (m^3).

From the food waste that we collected from Hawassa University the senior cafe is 255 kilograms of food waste per day from 1200 number of students we can produce 12.75 cubic meters per day of biogas that has a digester volume of 20.3148 cubic meters (m^3) and Cylindrical shape is selected based on its advantage as explained on the geometrical shape of the digester with a retention time of 60 days and the diameter (d) and height (h) of mixing pit are equal, which is 0.76 meter, 24.97 m^3. Here since the volume is small it does not need to divide and only specification is required for one digester.

AD technologies are typically optimized for either low solids or high solids content. Alternatively, they are referred to as wet or dry even though the feedstock generally has moisture content above 70%. Low solids refer to wastes with a solid content of 3%-10%, and high solids refer to a solid content of 15% or more. Wet digesters slowly mix feedstock with microbes to increase the speed of degradation. Water will need to be added to food waste in a wet digester to reduce solids content.

4.3. Design of Anaerobic Digester

A plant that will convert food waste in Hawassa Institute of Technology to biogas was designed in a suitable place within the campus. The Biogas plant was designed to contain the following major components. These are the Mixing pit, Digester Vessel, Outlet pit, and Biogas pipeline.

Table 6. *Dimensions and volume of the digester.*

No	Digester parts	Quantity with unit
1	Volume of digester	20.3148 m^3
2	Diameter of the mixing pit	0.76 m
3	Height of mixing pit	0.76 m
4	Diameter of digester chamber	3.82 m
5	Height of digester chamber	1.27 m
6	Volume of gasholder chamber	4.609 m^3
7	Volume of sludge chamber	2.848 m^3
8	Volume of fermentation chamber	17.514 m^3

5. Conclusion

The results of the project showed that the food waste type had significant effect on the substrate temperature and pH but had no significant effect on biogas production. From the result of the study, each of the food waste type produced the same quantity of biogas although the mixture treatment had the highest quantity to produce 12.75 cubic meters per day biogas from 255 kilogram of food waste per day, we have to design a fixed dome cylindrical Chinese biogas having a digester volume of 20.3148 cubic meters (m^3). from the food waste that we collected from Hawassa university of senior café that is 255 kilogram of food waste per day from 1200 number of students we can produce 12.75 cubic meters per day biogas that have digester volume of 20.3148 cubic meters (m^3). and Cylindrical shape is selected based on its advantage as explained on geometrical shape of digester with retention time of 60 day and the diameter (d) and height (h) of mixing pit are equal, which is 0.76 meter, 24.97 m^3. Here since the volume is small it is not needing to divide and only specification require for one digester.

Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste. It is a renewable energy source and, in many cases, exerts a very small carbon footprint. Biogas can be produced by anaerobic digestion with anaerobic organisms, which digest material inside a closed system, or fermentation of biodegradable materials. It is considered to be a renewable resource because its production-and-use cycle is continuous, and it generates no net carbon dioxide. Organic material grows, is converted and used and then re-grows in a continually repeating cycle.

Biogas upgrading is a technique applied to remove CO_2 and include removal of moisture and unwanted gaseous substance from produced biogases. This is done in order to enrich the methane content with the objective of increasing the calorific value of the gas. Biogas production also has economic benefits, reducing energy production expenditure and benefiting communities, especially rural ones in developing nations.

ORCID

0000-0001-8151-983X (Getahun Esubalew Demewoz)

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Agori, J. E., Nwoke, H., & Dike, B. (2021). Comparative Economic Assessment of Methane Gas and Liquefied Petroleum Gas (A Community Research Initiative for Patani, Delta State). (September).

[2] Alam, M., Binte, M., Mehnaz, M., Sharif, C., & Fahim, U. (2022). Production of biogas from food waste in laboratory scale dry anaerobic digester under mesophilic condition Production of biogas from food waste in laboratory scale dry anaerobic digester under mesophilic condition. Energy Nexus, 7(July), 100126. https://doi.org/10.1016/j.nexus.2022.100126

[3] Arifan, F., Abdullah, A., & Sumardiono, S. (2022). Kinetic Study of Biogas Production from Animal Manure and Organic Waste in Semarang City by Using Anaerobic Digestion Method Kinetic Study of Biogas Production from Animal Manure and Organic Waste in Semarang City by Using Anaerobic Digestion Method. (January). https://doi.org/10.22146/ijc.65056

[4] Benyahya, Y., Fail, A., & Alali, A. (2022). Recovery of Household Waste by Generation of Biogas as Energy and Compost as Bio-Fertilizer — A Review.

[5] Bezirhan, E. (2019). Production of bioplastic from potato peel waste and investigation of its biodegradability Production of bioplastic from potato peel waste and investigation of its biodegradability. (August), 4–9. https://doi.org/10.35860/iarej.420633

[6] Dong, X., Chen, W., Li, J., & Zhang, S. (2018). Research on biogas fermentation raw materials. 01030.

[7] Drosg, B. (2016). Process monitoring in biogas plants.

[8] Farghali, M., Osman, A. I., Umetsu, K., & Rooney, D. W. (2022). Integration of biogas systems into a carbon zero and hydrogen economy : a review. In Environmental Chemistry Letters (Vol. 20). https://doi.org/10.1007/s10311-022-01468-z

[9] Gebretsadik, H., Mulaw, S., & Gebregziabher, G. (2018). Qualitative and Quantitative Feasibility of Biogas Production from Kitchen Waste. 6(1), 1–5. https://doi.org/10.11648/j.ajee.20180601.11

[10] Heiker, M., Kraume, M., Mertins, A., Wawer, T., & Rosenberger, S. (2021). applied sciences Biogas Plants in Renewable Energy Systems — A Systematic Review of Modeling Approaches of Biogas Production.

[11] Hossain, S. M., & Hasan, M. (2018). Energy Management through Bio-gas Based Electricity Generation System during Load Shedding in Rural Areas. TELKOMNIKA Telecommunication, Computing, Electronics and Control. 16(2). http://doi.org/10.12928/telkomnika.v16i2.5190

[12] Load Shedding in Rural Areas Energy Management through Bio-gas Based Electricity Generation System during Load Shedding in Rural Areas. (April). https://doi.org/10.12928/TELKOMNIKA.v16i2.5190

[13] Jeremiah, M., & Kabeyi, B. (2022). Review Article Biogas Production and Applications in the Sustainable Energy Transition. 2022.

[14] La, U. S. O. D. E., En, E., Agricultu, L. A., I, W. R., Ariel, C. A., Ii, D. R., & Iii, Y. K. Z. (2021). Proposal for a Biogas Supply Network in the Rural Community “El Almirante” Propuesta de una red de suministro de biogás en la comunidad rural “El Almirante.” 30(3), 61–71.

[15] Marie, M., Yirga, F., Alemu, G., & Azadi, H. (2021). Heliyon Status of energy utilization and factors affecting rural households’ adoption of biogas technology in north-western Ethiopia. Heliyon, 7(March 2020), e06487. https://doi.org/10.1016/j.heliyon.2021.e06487

[16] Mukumba, P., Makaka, G., & Mamphweli, S. (2019). Design, construction and mathematical modelling of the performance of a biogas digester for a family, Eastern Cape province, South Africa. African Journal of Science, Technology, Innovation and Development, 0(0), 1–8. https://doi.org/10.1080/20421338.2019.1577028

[17] Mungwe, J. N., Asoh, D. A., & Mbinkar, E. (2021). Design Considerations of a Flexible Biogas Digester System for Use in Rural Communities of Developing Countries. 260–271. https://doi.org/10.4236/jsbs.2021.114016

[18] Musa, S. M., Makwayo, M., & Da, K. (2016). Biogas Productions from Food waste and Functional Working Methane Gas Digester Design. (March). https://doi.org/10.4010/2016.528

[19] Owhondah, R. O., & Gale, P. W. (2019). Optimization of small-scale low-cost anaerobic digestion system : Model based analysis. (July).

[20] Paladino, O. (2022). Data Driven Modelling and Control Strategies to Improve Biogas Quality and Production from High Solids Anaerobic Digestion: A Mini Review.

[21] Sarkar, M. A. R. (2018). Development of Biogas Processing from Cow dung, Poultry waste, and Water International Journal of Natural and Applied Science Original Article Development of Biogas Processing from Cow dung, Poultry waste, and Water. (July).

[22] Science, E. (2017). Water for small-scale biogas digesters in sub-Saharan Africa. 339–357. https://doi.org/10.1111/gcbb.12339

[23] Steiniger, B., Hupfauf, S., & Insam, H. (2023). Exploring Anaerobic Digestion from Mesophilic to Thermophilic Temperatures — Operational and Microbial Aspects.

[24] Tajebe, L. (2016). Bio-Gas Technology Adoption in Rural Ethiopia : It ’ s Effect on the Crisis of Deforestation. 6(1), 1–8.

[25] Tekle, T., & Sime, G. (2022). Technical Potential of Biogas Technology to Substitute Traditional Fuel Sources and Chemical Fertilizers and Mitigate Greenhouse Gas Emissions : The Case of Arba-Minch Area, South Ethiopia. 2022.

[26] Tjalfe, S., & Version, D. (2014). Bioenergy from agricultural residues in Ghana.

[27] Uche, A. M., Emmanuel, O. T., Paul, O. U., Olawale, A., Frank, K. B., Rita, O. O., & Martin, O. S. (2020). Design and construction of fixed dome digester for biogas production using cow dung and water hyacinth. 14(January), 15–25. https://doi.org/10.5897/AJEST2019.2739

[28] Van, D. P. (2020). A review of anaerobic digestion systems for biodegradable waste : Configurations, operating parameters, and current trends. 25(1), 1–17.

[29] Wang, Z., Hu, Y., Wang, S., Wu, G., & Zhan, X. (2023). A critical review on dry anaerobic digestion of organic waste : Characteristics, operational conditions, and improvement strategies. Renewable and Sustainable Energy Reviews, 176 (January), 113208. https://doi.org/10.1016/j.rser.2023.113208

[30] Waqas, M., Almeelbi, T., & Nizami, A. (2018). Resource recovery of food waste through continuous thermophilic in-vessel composting. 5212–5222. https://doi.org/10.1007/s11356-017-9358-x

[31] Wong, J. (2021). Sustainable Food Waste Management : Resource Recovery and Treatment Edited by. https://doi.org/10.1016/B978-0-12-819148-4.00002-6