ISLAMIC UNIVERSITY OF TECHNOLOGY

ORGANISATION OF ISLAMIC COOPERATION

Biogas Generation Potential from Food and Kitchen Waste

B.Sc. in Technical Education (Spec.: Mechanical Engg.) Thesis

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Department of Technical and Vocational Education (TVE)

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CERTIFICATE OF RESEARCH

The thesis titled "Biogas Generation Potential from Food and Kitchen Waste" submitted by Ismaila Sanyang (180032101), Kebba Ceesay (180032107), and Baboucarr A Bojang (180032103) has been recognized as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Technical Education (Spec.: Mechanical Engineering).

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DECLARATION

We hereby declare that this thesis titled " Biogas Generation Potential from Food and Kitchen Waste " is a genuine report of our study carried out as a requirement for the award of degree *Bachelor of Science in Technical Education (Spec.: Mechanical Engineering)* at Islamic University of Technology, Gazipur, Dhaka, under the supervision of Sayedus Salehin and Dr. Md. Rezwanul Karim, MPE, IUT during January 2020 to February 2021.

The matter embodied in this thesis has never been submitted in whole or in part to any other university/college for the award of any other degree.

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ABSTRACT

Organic waste is a type of unwanted material that is frequently produced as a result of man's activity, resulting in pollution of the environment. consequently, domestic biogas generation is one of the most acceptable methods for treating biomass wastes because it supplies energy while also addressing ecological, financial, and climate change concerns. Bio-energy supplies counter both energy scarcity and dependency on polluting and non-renewable resources as a result of advanced biogas extraction technologies. These have contributed to the introduction of a range of biogas equipment for cooking, lighting, and electricity production.. In this study, an attempt has been made to determine the methane generation potentials from food and kitchen waste, from a university cafeteria, as a renewable energy resourc by using a simple mathematical calculation to evaluate the total biogas production as well as to design a fixed dome digester and hydraulic tank. The result shows that the total gas produced, the daily charge, and organic loading rate are $8.75m^3$, $0.3017m^3$/day, and 17.402kg substrate / m^3 / day, respectively. It also presents the total volume of the digester, diameter, and volume of the digester, volume, and diameter of the hydraulic chamber as $22.183m^3$, 3.676m, $18.103m^3$, $4.524m^{3,}$ and 2.025m, respectively.

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CHAPTER 1 INTRODUCTION

1.1 Background

Anaerobic digestion is the collection of processes where microorganisms breakdown biodegradable matter in the absence of oxygen. Anaerobic digestion is very important for waste management because microorganisms produce a substance called biogas which is a combination of carbon dioxide, and methane. In this process, methane is our target because is flammable and can be used as an energy source. Waste generation is rapidly increasing and it is creating a lot of trouble for developing countries in terms of its disposal and management. The main cause of waste generation has been traced to the growth of population and urbanization. Waste management has become a global problem for the entire world. There is a growing concern among people about the development of waste and its effects.

Bangladesh for instance is one of the most heavily populated areas in the world, with a population of 120 million in total and 755 per square km in density. 81% of the population lives in the rural region and the remaining 19% live in the urban zone[1]. In Bangladesh, the major cause of municipal solid waste in Dhaka is domestic waste, highways, market places, hospitals and clinics, and private enterprises. Currently, Dhaka City produces roughly 3500-4000 tons of solid waste per year[2]. Due to these huge amounts of waste, transportation have become a problem. The only possible solution is to use them as a source ofrenewable energy which provides clean reliable and safe energy production. Reducing greenhouse gas emissions, particularly CO_2, has become more relevant worldwide. Much of the CO_2 released into the atmosphere is the product of anthropogenic practices arising from the use of fuel in the transport and electricity industries.

Fig. 1 Biogas plant in Germany[3]

1.2 Why Biogas

Biogas is the process in which microorganisms breakdown organic matter such as carbohydrates, fats, and protein in the absence of oxygen. Biogas can be obtained from the substance like waste of agricultural products, manure, food waste, municipal solid waste, plant materials,etc. During anaerobic decomposition, biogas is made from organic remains through different sets of anaerobic bacterial interactions. As various bacteria consume certain organic compounds, anaerobic decomposition is a two-stage process. In the first level, acid bacteria break organic molecules into glycerol, peptides, alcohol, and thus the simpler sugars. Methane is created with the aid of the second bacterium after these complex materials are developed in appropriate quantities. These methane-generating bacteria are highly affected by environmental conditions, which can completely interrupt or slow down the operation. The key benefits of biogas are manyfold, it is a renewable energy resource, it reduces greenhouse gas emissions, reduces solid waste volumesI,disposal space and cost and recovers value from waste There are a range of urgent concerns related to the discovery of other energy sources due to energy independence, volatility in fuel prices, the danger of global climate change, and projected depletion of non-renewable sources of fuel [4]

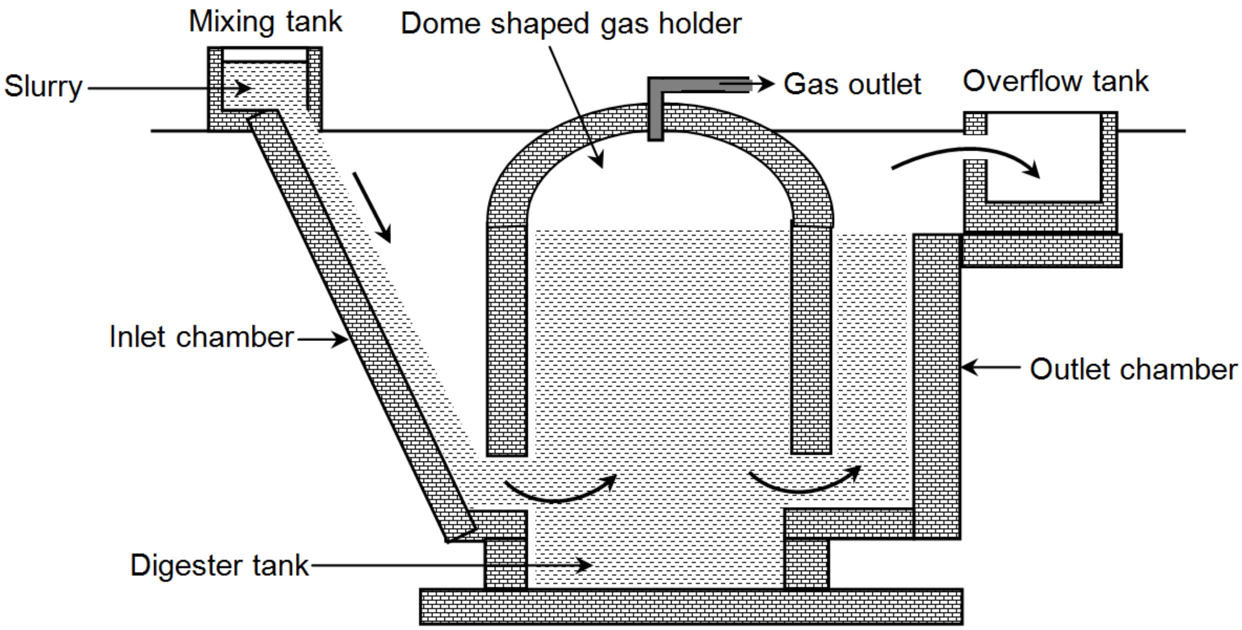

Fig. 2 Fixed dorm digester[5]

1.3 Working principles

The process starts in the mixing chamber where the organic waste material is mixed with some percentage of water and is fed in the digester through the inlet chamber. The fermentation process takes place in the digester where methanogenic bacteria act on the organic waste to produce methane. The gas will be present on the top part of the dome and eventually be passed through the gas outlet. Finally, the pressure of the gas will push the slurry through the outlet chamber into the overflow tank (slurry tank).

1.4 Research Objective

A substantial reduction in pollution may also be achieved in the energy sector. The industry by efficiency improvement through the use of other fuels. We can save CO_2 emissions in the atmosphere through the use of biogas plants[6]. In heavily populated areas where people have little access to sustainable modern sources of energy[7], these supplies are diminishing in no time. Renewable sources include biomass, solar, wind, geothermal among others. But each one has its own benefits, and risk factors that closely interfere with other governmental and global goals. Choices need to be made, but with some recognition that choosing an energy strategy necessarily means choosing an environmental strategy.Renewable energy is expected to reduce the dependence of mankind on fossil fuels. As part of Fuel diversification, the relevant strategies have been adopted in Bangladesh program [8]. In addition to aerobic composting, anaerobic digestion can be an alternative method for MSW reduction. Unlike aerobic composting, solid waste anaerobic digestion does not require air and creates biogas with high levels of volumetric methane fraction (50-70 percent)[2]. Furthermore, the anaerobic digestion methods are ideally suited to wet waste and the area requirements are satisfactory [9][10]. ,Currently, Dhaka City produces roughly 3500-4000 tons of solid waste per year. The per capita production is 0.5kg/day per day. The density of the 600 kg/m^3 of solid waste is estimated to be[2] . The outcome, according to research carried out by Japan International Corporation Agency (JICA 2005), from 2004 onward, The overall residue from household waste pf a population of 5.728 million, the source was calculated to be 1945 t/d, with an average generating rate of 0.34 kg/day per day, per person[2]

Bangladesh is one of the most heavily populated areas in the world, with a population of 120 million in total and 755 per square km area. 81% of the population lives in the rural region and the remaining 19% live in the urban zone[1]. As a country focused on agriculture, Bangladesh has incorporated a lot of Biomass that has been used for energy production, via direct burning, or through biomass gasification. Almost 80 percent of the country's population relies heavily on agriculture[5]. Massive quantities of vegetables are available during the winter seasons which can be a potential source of kitchens Rubbish. Because of the lack of appropriate transport and preservation, these huge quantities of waste can be used as a source of biogas [11]. Most solid waste is produced due to urbanization, and their successful disposal is a topic of importance. On the other side, these wastes have a positive side, owing to their organic nature, they have a biogas generation ability. This study aims to determine the potentials of kitchen waste as a renewable energy resource. In this study we intend to use a mathematical model to evaluate the total biogas production as well as to design the biogas digester. It is therefore anticipated that such studies would provide a clearer understanding of anaerobic biodegradation which can be used for design and scale-up purposes later on.

1.5 Literature Review

Waste management has been challenging for the developing countries, and the rest of the world. Its management has become an environmental and social concern due to the continuous increase in solid waste generated and therefore the large environmental impacts of its improper treatment. Anaerobic digestion proves to be the solution to this problem. A significant number of studies have been carried out worldwide to investigate the feasibility of generating biogas from waste. Up to the 1970s Anaerobic digestion (AD) is used commonly for the purification of wastewater alone [3]. In 1997 a research was conducted using a material mixture of the organic fraction of municipal solid waste and main sewage sludge. A reactor tank was established and is operated for some days at mesophile temperature. A two-stage mathematical model of acidogenesis and methanogenesis was developed and validated using experimental results. The study shows the result of a lab experiment of anaerobic digestion and again it shows the application and development of a mathematical model of anaerobic digestion[12]. Biswas et al. [13] also carried out a detailed analysis on the kinetics of biogas and the use of urban waste as the source of biogas. On a separate study, Biswas et al. [14] developed a statistical deterministic approach to predict the functionality of an anaerobic digester Satisfactorily produced biogas.

Research was carried out to analyze the sources of biogas feedstock from biomass and agricultural waste, the potential of the development and utilization, the biogas technologies used, as a driving forces for Thailand future prospects[15]. Again in 2006, another research was conducted by Kale et al. where they built a biogas farm that extracts biogas from kitchens using thermophilic microorganisms. The biogas plant was equipped with a crushing mixer/pulper. The solid waste, the premix tanks, the pre-digester tank, the solar water heater, the main digestion tank, the manure pits, and the gas lamps for the biogas provided by the plant [16]. An Italian researcher also conducted a socio/economic and environmental aspect of biogas generation using rural household waste research. In his study, he learned that anaerobic digestion from vegetable waste, which small households generate daily, adequate biogas can be produced for daily cooking of these households [17]. Tomei et al. established the key goal of anaerobic digestion of sludge to be the breakdown and dissolution of organic matter, with the subsequent stabilization of sludge and mitigation of pathogens[18]. To obtain biogas, three(3) types of cotton waste were anaerobically processed for 23 days and the experimental outcome proves to be a better source[19].

Description models for anaerobic digestion range from steady-state to very complex dynamic models [18]. The IWA ADM1 developed by the corresponding IWA Task Group is the most up-to-date model currently. The ability of this model to predict the key processes occurring in an anaerobic digestion system has been defined by Batstone et al. and serves as a unified basis for anaerobic digestion modeling [20]. in particular, from vegetable waste and in this sector, India is one of the leading countries. Kameswari et al. Built a 30-ton capability indicator plant biomethanation of waste from the vegetable market per day. The biomethanation plant was planned to generate 30 tons per day, organic loading rate of two 0.5 kg VS/day/m^3 of 2.5 kg VS/day/m^3 Production 2500 m^3 of biogas per day[21]. For the Kamaraj, S. research, vegetable market waste was the source for the feedstock. Through this analysis, he concluded that for the production of biogas, vegetable waste may be used using a biphasic system[22]. An aluminum digester was built and operated in a batch system. The output of biogas has been observed to rely heavily on the temperature of the slurry and the retention time is almost 85 days[23]. Anjum et al.

also showed that some percentage of melon remains can be used as a co-substrate to increase the biodegradability of the production of OFMSW and biogas[24].

To calculate the methane yield, a first-order kinetics model was developed. From various food waste mixtures and unscreened dairy manure and the estimated model results presented that adding food waste to a manure digester at levels up to 60 percent of the initial volatile solids substantially improved the yield of methane for 20 days of digestion [25]. Nuntiya et al. analyzed to estimate the biomass capacity of the chosen feedstock. The most promising potential for industrial biogas production is shown by cassava flesh, pineapple leftover, pineapple skin, and palm oil empty fruit (EFB) branches, in decreasing order [26]. The feasibility of anaerobic co-digestion of high-yield glycerol and sewage sludge has been studied at 35 ^{0}C. It was concluded that the addition of crude glycerol at 1 percent v/v increased the output of CH_4 in the reactor beyond the predicted theoretical value, as it was completely digested and further improved the growth of the system's active biomass [27]. In anaerobic digestion of food waste, ammonia aggregation is theoretically observed, thus limiting its use in industrial biogas plants. A research was conducted to examine the suitability of the nitrification process in the recirculated anaerobic digestion system to extract ammonia from food waste digestate[28].

In 2013, a study was carried out to assess the performance of several kitchen waste ratios in a metal-built portable floating style biogas plant with a volume of 0.018 m^3 for New Delhi, India in outside climatic conditions. 30 kg slurry capacity of each biogas plant in the batch system for all measurements. The temperature, solar radiation, and relative humidity were measured during these times. It shows that this study can be improved if the different ratios of kitchen waste were compared under aluminum made and it is a better option since it is safe for the environment and due to having several other benefits [6]. Substratum compositions with a small C/N ratio are viewed difficult to control and can lead to process breakdown, although industrial garbage products rich in protein have great potential for biogas generation. By using protein-rich substrates, this common belief has been challenged [29].

A biogas plant for wet digestion was installed at the Islamic University of technology using rice as the only source of waste and estimating the methane output rate by PROII tools. Ultimately, the simulated and experimental observations were compared. It was further concluded that to improve the system the load and unload of the system needs to be learnt based on yields and seasonal gas needs. Also, different scale system needs to be adopted to standardize and optimize the system. Another study was conducted to offer a simpler model that forecasts the amount of biogas generated which could be applied to agricultural energy. The results show that the model forecast settings that cannot exist in real life situation but was later modified to be practical with a control mechanism. The outcome only provides the optimum capacity for biogas, since neither non-degradable material nor non-degradable material is encouraging. A comparative and analytical study was done on different sources of waste such as cow manure, sewage sludge, kitchen saste & hyacinth water for biogas generation and the result shows that adding sewage sludge with cow manure can enhance reaction, increased production, and an improved methane content [8]. Andriet al. made an assessment to determine the production potential of biogas using five raw and processed agricultural waste: papaya peels, soybean residues, rice straws, sugarcane bagasse, and larger galangals were studied using both batch digestion methods and a process of continuous digestion. The result shows the average biogas production rate and the highest biogas yield[30].

CHAPTER 2 MATERIALS AND METHOD

2.1 Source of waste and sample collection

Solid waste (food /kitchen) residues for the experiment were supposed to be collected from the student cafeteria of Islamic university of technology (IUT). The waste comprised mainly peels of different vegetables (onion, ginger, garlic, cucumber, carrot, papaya, sweet pumpkin) for the kitchen waste and the food waste comprises cooked rice.

The data of the solid waste (food/vegetable) for the research was collected from the cafeteria of Islamic University of Technology (IUT). If the experimental setup has been built, water would have been collected from the main water supply line of the university. The solid waste (food/vegetable) would have been fed into the digester by diluting it with water. The solid waste (food/vegetable) would have been manually mixed with water without shredding or any pretreatment. At present, Islamic University of Technology (IUT) generates about 175kg of solid waste (food/vegetable). This estimated result is only for one cafeteria (south cafeteria). By summing up both cafeteria North and South we can rightly conclude that IUT generates 175 kg x 2 which is 350kg of solid waste (food/vegetable) per day.

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Table 1. Basic information on the physical properties of the substances [31]

Types	**Quantity**
Density of food waste	1160 kg/m^3
Water content of food scrape	70%
Organic content of food waste	85%
Mesospheric Temperature	25%
Average solid concentration	8%
Retention Time	60 day
Energy content of biogas	38MJ/m^3

2.2 Data Analysis

The data has been collected after visiting the cafetaria and interviewing the staff members involved in processing and cooking the meals at the cafetaria. Upon collection of data, the following analysis has been conducted.

Average mass food waste = 145kg /day = 4350 kg/month

Average mass of kitchen waste = 30kg/day = 900 kg/day.

Volume of food and kitchen wastes per day = (145kg/day+30g/day)/1160kg/m^3 = 0.1509m^3 / day.

Now having a wet waste we need to apply one to one ratio meaning an equal amount of waste and water.

Volume of daily charge (D_c) = 0.1509*2 = 0.3017m^3/day.

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

Volume of digester (D_v) = D_c*HRT= 0.3017m^3/day*60day = 18.10m^3

Assume that ratio of volatile solid to total solid is 90%.

The organic loading rate(OL_R) = (Dc * S)/Dv = (0.3017 * 1040)/18.10 = 17.402

Where:

S: is Concentration of VS in the input [kg/m^3]

Hence S=1160 kg/ m^3 * 0.9 = 1040 kg/ m^3

Gas production rate from food waste = 0.05 m^3/kg [31]

2.3 Total gas produced

The total gas output from food waste is calculated as the volume of food waste per day and the rate of gas production from the food waste

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

=175*0.05 = 8.75m^3

2.4 Designing of a Digester

In designing a digester, a fixed dorm digester is chosen which allows fertilizer and gas to be continuously produced and predictably. A retention time of 60 days is selected to allow the bacteria to have sufficient time to react to the waste.

As for the diameter, since the hydraulic tank is cylindrical, therefore its height is equal to its diameter (d=h).

For determining the diameter, the equation 1 is used.

$V= \pi d^2 h/4,$ (1)

Where V is the daily charge of the waste after giving a safety factor of 10 percent, then the amount including the safety factor (V)

$V= (10\%*0.3017m^3/d)+0.3017m^3/d = 0.33187m^3/d$ (2)

As for the dimension of the compensation tank around 20% of the volume of the digester (slurry) is the dimension of the compensation tank (V_{tank}).

2.5 Cross-section of the digester

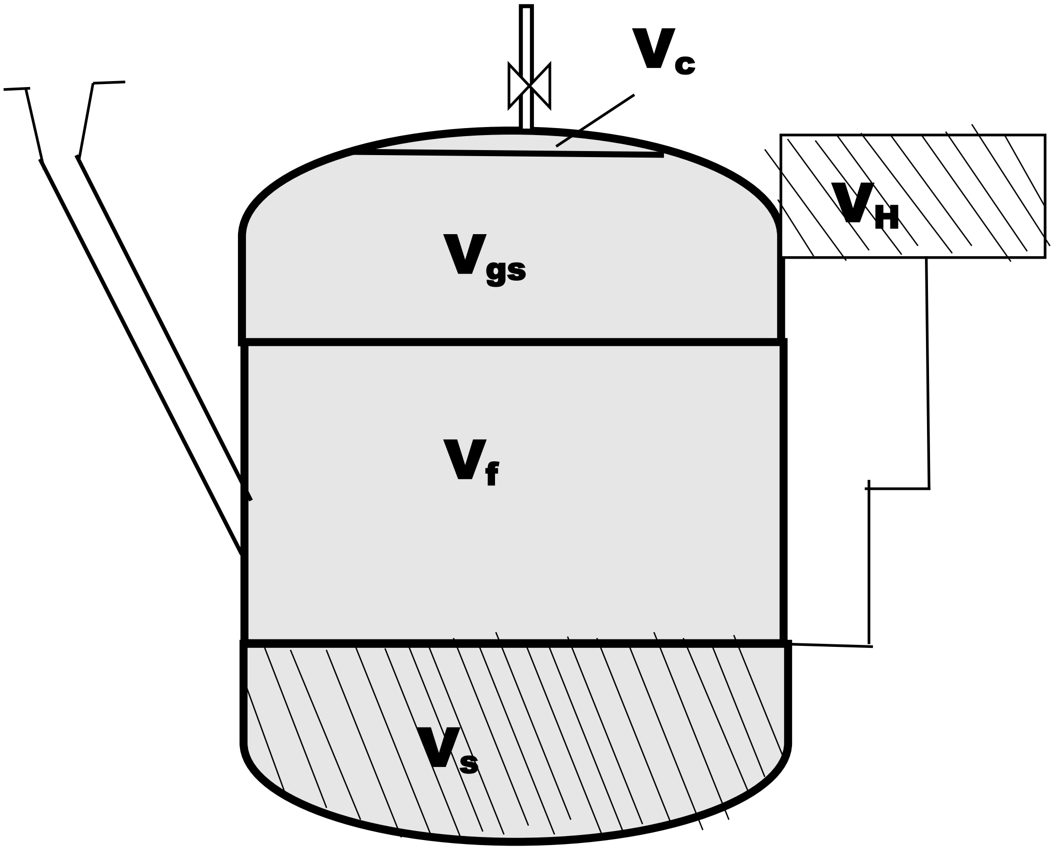

Fig. 3 Cross- section of a digester plant

a) Gas collecting chamber volume = V_c

b) Gas storage chamber volume = V_{gs}

c) Fermentation chamber volume = V_f

d) Sludge layer volume = V_s

e) The crown radius of the bottom(R1) and upper(R2) spherical layer of the digester.

f) The surface area of the upper and bottom dome S1 and S2 respectively.

g) The maximum distance of upper and lower dome f1 and f2 respectively.

Consequently,

The Total volume of the digester (V) =V1+V2 + V3

2.6 Geometrical Dimension of the Cylindrical Shaped Biogas Digester

The fixed dome digester is expressed by the following correlation for structural stability and effective performance [31].

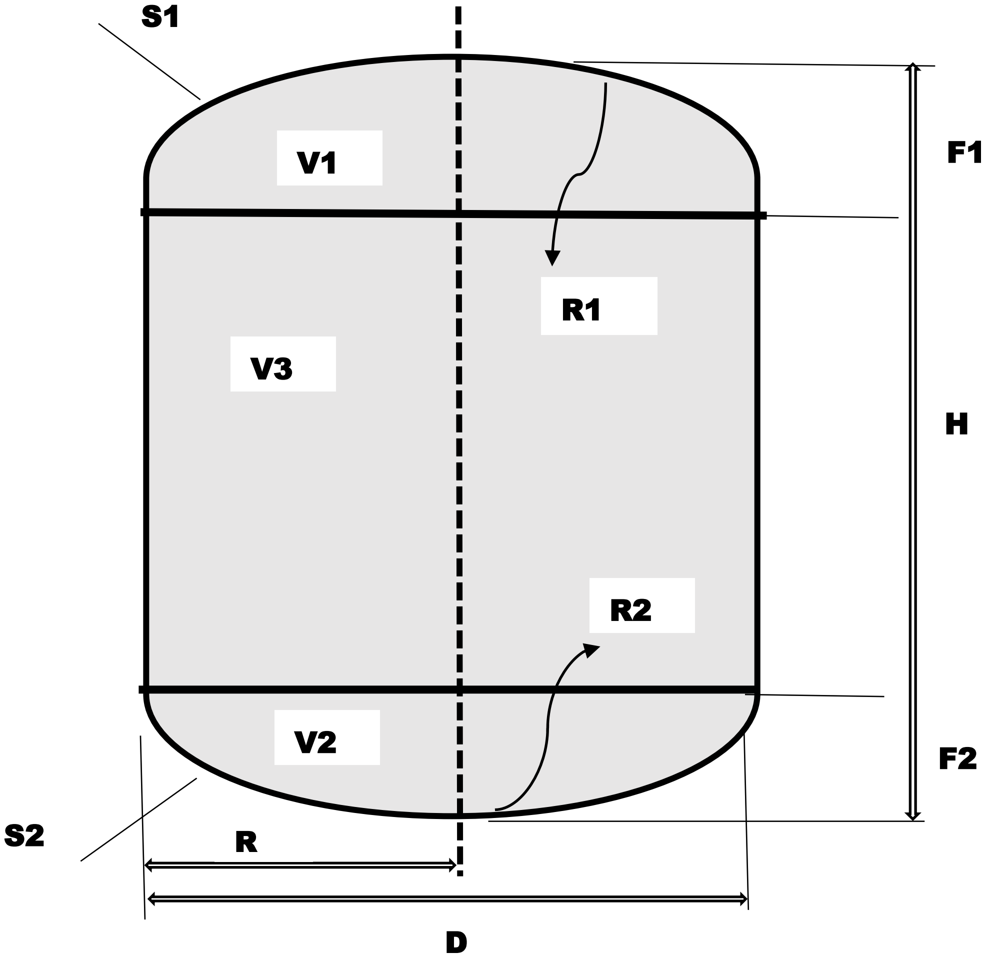

Fig. 4 Cylindrical Shaped Biogas Digester

Table 2. Correlation for fixed dome digester[31]

For Volume	For geometrical dimensions
$V_c \leq 5\%$ V	D=1.3078 X V1/3
Vs ≤ 15% V	V1= (0.0827) D^3

$V_{gs}+ Vf = 80\% V$	$V2 = (0.05011) D^3$
$V_{gs}= VH$	$V3 = (0.3142) D^3$
$V_{gs} = 0.5 (V_{gs} + V_f + V_s) K$	$R1= (0.725) D$ $R2= (1.0625) D$
Where K = 0.4m3/m3d Gas production rate per m3 digester volume per day	$f1 = (D/5)$ $f2 =(D/8)$
	$S1 = (0.911) D^2$ $S2 = (0.8345) D^2$

2.7 Determining the volume of the Digester Chamber

Digester volume (Dv) = V3+ V2

$18.10m3 = (0.05011+0.3142) D^3$

D = 3.676m

Since the diameter is determined, now substitute it in the table above to find the value of each given parameters.

- R1 = 0.725D = 0.725*3.676 = 2.6651m
- V1 =0.08227D^3 = 0.08227*3.676^3 = 4.0867m^3
- S2 = 0.8345D^2 = 0.8345* 3.676^2 = 11.2766m^3
- V3 = 0.3142D^3 = 0.3142*3.676^3 = 15.607 m^3
- V2=0.05011D^3 = 0.05011*3.676^3 = 2.489 m^3
- F1 = (D/5) = 3.676 /5 = 0.7352m
- F2 = (D/8) =3.676/8 = 0.4595m
- S1 = (0.911) D^2 = 0.911*3.676^2 = 12.31 m^3
- R2 =1.065D = 1.065* 3.676= 3.9149 m
    - Total Volume (Vtot) = V2+V3+V1 = (2.489 + 15.607 + 4.0867) m^3

$= 22.183\text{m}^3$

- $V3 = (3.14 * D^2 * H)/4$

$15.607 = (3.14*3.676^2 * H/4$

Therefore, H= 1.47m,

2.8 Volume calculation of hydraulic chamber

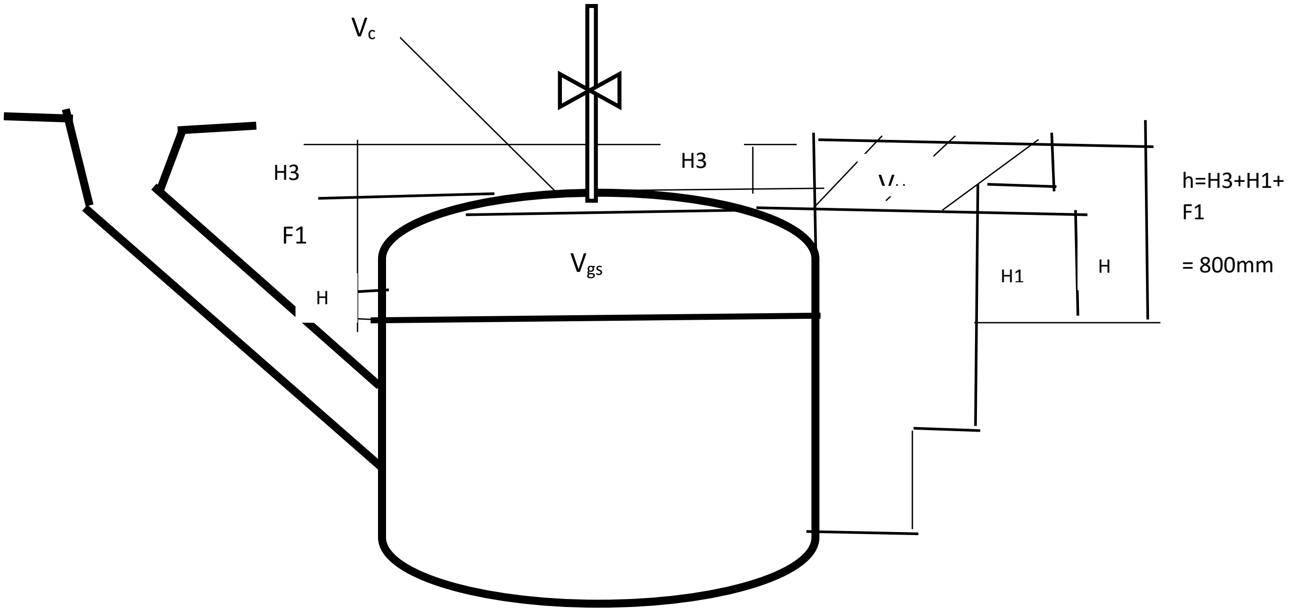

Fig. 5 A design showing hydraulic chamber of a digester

From geometrical assumptions:

- V_c= (0.05) V = 0.05*22.183m^3 = 1.10915m^3

- V_{gs} = k(V_f+V_s)/2-k (where k is the Gas production rate)
- V_{gs}= 0.5(15.607+2.489)/2-0.4

  = 4.524
- From the Geometry, we know that,

  V1 = V_{gs} + V_c, Now

  V1- (3.14*D^2 * H1/4)

  4.0867 – ((3.14*3.676^2 *H1)/4

  H1 = 0.385m

- “The value of the height of the above dome up to the end, have a fixed **h** = 800 mm water volume (I mm = 10 N/ m^2)”[31].

  h = H3 + H1 + F1

  0.8 – (0.7352 + 1.47)

  H3 = 1.4052m.

- Again, we know that

  V_{gs} = V_H

  4.524 m^3= 3.1416 * H3/4 * D_H^2

  D_H = 2.025m, which is diameter of hydraulic chamber

CHAPTER 3 DISCUSSION AND RESULTS

The calculation shows that the total gas produced is 8.75m^3, methane constituent 55%-60% and carbon dioxide also forms 30%-35% of this value. Other studies have shown that biogas production is dependent on the temperature and solar intensity of the atmosphere also the slurry temperature is always greater than the ambient temperature.

Table 3. Key results from the study

Volume of food and kitchen wastes per day	0.1509m^3 / day
Volume of daily charge (Dc)	0.3017m^3/day.
Volume of digester (Dv)	18.10m^3
Total gas produced	8.75m^3
Total Volume of the Digester	22.183m^3
Diameter of the Digester	3.676m
Diameter of the hydraulic Chamber	3.676m
Volume of the hydraulic chamber	4.524 m^3

Again some studies also shows that the surrounding temperature has an effect on the inside temperature of the digester. So when the ambient rise the inside will also rise. Mostly the volume of the digester for small scale plant is about 10- 13 m^3 but our design is a bit higher that this margin which means we going to have production because the bigger the digester size the more the methane production.

CHAPTER 4 CONCLUSION

Biogas digester design and implementation have been studied and presented in this study. Selecting a digester type and size, retention time, the total amount of waste used, Ph, temperature, total solid content, and volatile solid are important factors to consider during designing to generate optimal methane production. Several studies have shown that biogas plant is liable to faults in the construction of the digester, inlet and outlet chamber, mixing device, and also leakages due to cracks. When using food and kitchen waste as a source, cow dung may be added to quickly speed up and start the process easier for the generation of bacteria.

Biogas plant was not installed practically due to pandemic (COVID-19) but we hope the IUT administration will consider building it in the near future. The gas produced will be of a great supplement and cost saving, will mitigate the amount of kitchen air pollution associated with cooking, which would affect the overall health of the cafeteria staffs, consequently Improving their working standards and the environment they operate in.

The bio-slurry produced after methanogenic process can be used as a source of fertilizer for plantation and gardening within IUT, which can also reduce the cost of buying the fertilizer.

Adding the second cafeteria waste would enhance the overall output of gas production which can eventually replace IUT's entire dependence on natural gas and firewood and can even be used in the future for electricity generation and heating during the cold season.

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