

Palestine Polytechnic University

College Of Engineering And Technology



Biogas Filter

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Submitted to the College of Engineering in partial fulfillment of the requirements for the Bachelor degree in Automotive Engineering

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Palestine Polytechnic University

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Mechanical Engineering Department

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Abstract

The amount of biomass waste is rapidly increasing worldwide. Besides, the energy demand is also increasing. Utilizing biomass for production of biogas is one of the most promising methods for producing energy renewable resource. This project aims at investigating yield and composition of produced biogas produced from anaerobic digestion for single feed stock (cow manure). This work presents an experimental study of purification of a biogas by removal of its hydrogen sulphide (H_2S), Ammonia (NH_3), Siloxanes(VOCs), methane(CH_4) contents by using filter.

المخلص :

تزداد كمية النفايات بشكل هائل في العالم، بالإضافة الى ذلك فإن الطلب على الطاقة يزداد ايضاً. إن تحويل الغاز الحيوي إلى غاز الميثان النقي هو أحد أكثر الطرق الواعدة لإنتاج مصدر من مصادر الطاقة المتجددة. يهدف هذا المشروع إلى دراسة تركيب الغاز الحيوي الناتج من مخلفات الابقار حيث تتم فلتريته بمروره بعدة عمليات للتخلص من المركبات الضارة للحصول على غاز الميثان النقي، وبعد الحصول عليه يتم ضخه إلى محرك المركبة لتشغيلها لاحقاً.

الإهداء

إلى فلسطين ودُرتها القدس وَ تاجها الأقصى
وَ لِمَن افتداهَا بِرُوحِهِ فارتقى شهيدا
وَ لِمَن ضحى لها بسنين عُمره فَعَدَى أسيرا
وَ لِكُلِّ المُرابطين على ثراها الطاهر.
إلى مَنْ قضى الله تعالى في كتابه الإحسان إليهما
مع توحيدهِ بالعبودية فلا نستطيع رد نزر من إحسانهم إلينا
" أبي وأمي "
أنثما حياتي كلها, لكم مني فؤادي فاقبلوه
إلى مَنْ وَقَفَ على المنابرَ وَ أعطى من حصيلة فكره لِينير دُربنا ...
إلى الأساتذة الكرام ...
لِكُلِّ مَنْ دَعَمَنَا وَ وَقَفَ بِجانِبينا...
لِزَميلاتنا وَ زَملائنا مُهندسي وَ مهندسات المُستقبل ...
إليكم جميعاً نُهدي فاتحة العطاء على أمل البقاء بإذن الله تعالى

الشكر

الحمد لله الذي بفضلہ تتم النعم والصلحاحات... الحمد لله الذي أنار قلوبنا وعقولنا
الشكر لله , واهب عقلنا , رازقنا نعمه ... الشكر لله أولا و أخيرا على حسن توفيقه وكریم عونه
الشكر لكل من علمنا حرفاً لكل من أنار دربنا ولم يبخل علينا بمعلومة او بعلم
الشكر لوالدينا الاعزاء شكرا لثقتكم و دعمكم لنا
الشكر لكل من مد لنا يد العون جزاكم الله عنا خير الجزاء

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Chapter One

Proposal

1.1 Introduction

1.2 Scientific Background

1.3 Problem definition (Problem statement)

1.4 Research Questions

1.5 Goals and Objectives

1.6 Advantages

1.7 Significant of study

1.8 Research methodology

1.9 Budget

1.10 Action plan

1.1 Introduction

1.1.1 What is biogas?

Biogas is a flammable gas, which is produced by biomass fermentation. Biogas typically refers to a gas produced by decomposition of organic matter in the absence of oxygen and it's a kind of biofuel. Biogas is a source of renewable energy sources that are used to produce electricity and heat, but the best upgrade is to use this clean energy as fuel for vehicles. Biogas is worth using rather than natural gas because of its renewable sources.

Biogas can damage the environment because of the presence of contaminated hydrogen, that harmful to humans and animals. At lower concentrations, this gas has an unpleasant odour; at higher concentrations, it can be life-threatening. The recommended industrial exposure limits are from 8 to 10 ppm for 8 hours a day per week (Horikawa, 2001).

On the other hand, Biogas is a rich source of energy because it contains a high amount of methane. However, direct use of biogas as fuel without removal of H₂S leads to the formation of Sulphur dioxide (SO₂), which is another toxic pollutant and a major contributor to acid rain in the atmosphere.

1.1.2 How is biogas generated?

The biogas is a non-fossil gas which is produced from landfills, food, sewage, organic waste such as dead plants and animal's material, animal's dung, and kitchen waste.

1.1.3 Composition of biogas [1]?

- Methane (CH₄): 45 -75 %.
- Carbon Dioxide (CO₂): 25 -45 %.
- Trace components: 2 -5 %.
- Carbon Monoxide (CO), Nitrogen (N₂), Oxygen (O₂), Hydrogen (H₂), Hydrogen Sulphide (H₂S), Ammonia (NH₃) and Siloxanes (VOCs).
- Water (vapor, saturated): 2 –7%.
- Dust particles.

1.2 Scientific Background

Global demand for energy is increasing, and about 88% of this demand is met at nowadays by fossil fuels. Scenarios have shown that the energy demand will increase during this century by a factor of two or three [2]. At the same time, concentrations of greenhouse gases (GHGs) in the atmosphere are rising rapidly, with fossil fuel-derived CO₂ emissions being the most important contributor. In order to minimize related global warming and climate change impacts, GHG emissions must be reduced to less than half of global emission levels of 1990 [3]. Another important global challenge is the security of energy supplies, because most of the known oil and gas reserves are concentrated in politically unstable areas. In this context, biogas from waste will play a vital role in the future. Biogas is a renewable energy source, which can be used to replace fossil fuels in electricity and power production, and can also be used as a fuel for gaseous vehicles. Biogas rich in methane (biomethane) can replace natural gas to produce chemicals. The production of biogas through anaerobic digestion provides many advantages. It has been evaluated as one of the most energy efficient and environmentally beneficial technology [4]. It can drastically reduce GHG emissions compared to fossil fuels by utilization of locally available resources. The digestate is an improved fertilizer in term of its availability to crops which can substitute mineral fertilizer. The European energy production from biogas reached 6 million tons of oil equivalents (Mtoe) in 2007 with a yearly increase of more than 20% [5]. Germany has become the largest biogas producing country in the world, thanks to the strong development of agricultural biogas plants on farms. At the end of 2008, approximately German farms [6]. Within the agricultural sector in the European Union (EU), 1,500 million tons of biomass could be digested anaerobically each year, and half of this potential is accounted for by energy crops [7]. The different aspects of agricultural biogas production and utilization are reviewed in this paper.

1.3 Problem definition (Problem statement)

The main problem in this project is the presence of many harmful substances that come out with biogas which are a group of: Methane(CH₄), Carbon dioxide(CO₂), Hydrogen sulphide(H₂S), Ammonia(NH₃), Siloxanes(VOC's), Water vapor.

This project will solve the problem of the presence of these substances through several processes that remove them to obtain pure methane. There will be many users and beneficiaries of this project whether they are companies, factories, people.

1.4 Research Questions

1.4.1 Main Research question

- Is there possibility of use pure methane to run an engine ?

1.4.2 Sub-questions

- What is the composition of the produced biogas?
- What is the effect of fermentation time on the amount and composition biogas?

1.5 Goals and Objectives

The main goal of the present study is to investigate the effects of biogas filter on composition of the produced biogas.

The project targets the following specific objectives:

1. Stopping wasting the biogas potential.
2. Saving money by selling biogas-fuel.
3. Saving money by purchasing biogas-fuel instead of diesel fuel.
4. Avoiding polluting emissions.
5. Avoiding noise pollution.
6. Design a filter to make methane pure.

1.6 Advantages

- Waste treatment and disposal safely
- Methane is one of the best gas because it does not produce smoke and environment friendly
- solve sewage problem

1.7 Significant of study

Biogas is promising technologies have advantages and benefit for the society. biogas represents a flexible and efficient renewable energy source that reduced dependency on imported fossil fuels, reduced greenhouse gas emissions and mitigation of global warming. Also usage of organic waste in biogas production helps in waste reduction, job creation.

1.8 Research methodology

The following methodology will be adopted to work in our project:

1. Obtain the required sample from the cow dung
2. We fermenting sample under certain conditions of heat
3. The output of the sample gas passes through filter that contains Sensors before it
4. Get rid of impurities inside the filter
5. Out of pure methane through sensors to make sure that there is no impurities.
6. Documentation of project thesis

1.9 Budget

The following table (1.1) list that the total cost for the project is about 4150₹.

Table 1.1: Budget table

Steps	Cost(₹)
Compressor	100
Pipes, valves and mechanical joints	600
Component inside filter	300
Filter body	3000
Tube	150
Total Coast	4150

1.10 Action plan

1.10.1 Action plan for first semester

The action plan of our project is illustrated in table (1.2) below for first semester.

Table 1.2: Action plan for the first semester

TASKS	1 st Month				2 nd Month				3 rd Month				4 th Month			
	Wk ₁	Wk ₂	Wk ₃	Wk ₄	Wk ₁	Wk ₂	Wk ₃	Wk ₄	Wk ₁	Wk ₂	Wk ₃	Wk ₄	Wk ₁	Wk ₂	Wk ₃	Wk ₄
Identification of Project Idea	■	■	■													
Collecting Data			■	■	■	■	■	■	■	■	■	■	■			
Preparation of equipment								■	■							
Documentation		■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Presentation of First Semester																■

1.10.2 Action plan for second semester

The action plan of our project is illustrated in table (1.3) below for second semester.

Table 1.3: Action plan for the second semester

TASKS	1 st Month				2 nd Month				3 rd Month				4 th Month			
	Wk ₁	Wk ₂	Wk ₃	Wk ₄	Wk ₁	Wk ₂	Wk ₃	Wk ₄	Wk ₁	Wk ₂	Wk ₃	Wk ₄	Wk ₁	Wk ₂	Wk ₃	Wk ₄
Design of project			■	■	■	■	■	■	■							
Collecting Data			■	■	■	■	■	■	■	■	■					
Analysis the system							■	■	■	■	■	■	■			
Test the project											■	■	■	■		
Documentation														■	■	
Presentation of Second Semester																■

Chapter Two

Fermentation system

2.1 Introduction

2.2 History and future trend of biogas

2.3 Biochemical process of anaerobic digestion

2.4 Types of biogas plant

2.5 Factors affecting AD process for biogas production

2.1 Introduction

Anaerobic Digestion (AD) is the process whereby organic matter is broken down by bacteria and enzymes in an oxygen-free environment. The organic matter is released as biogas; this is a mixture of the combustible gas methane (50-75%), carbon dioxide (25-45%), small amounts of water (2-7%) and trace gases. This process occurs in bogs, landfill and in the stomachs of animals. The type of feedstock used by anaerobic digesters varies; it can include pig or cattle slurry, food waste, energy crops (grass silage, maize-silage, grain), municipal solid waste from households and organic solid waste from industry. Materials with high lignin content, e.g. any kind of wood, are not suitable for biogas production. Feedstock is pumped into a closed vessel (digester) which has been inoculated with suitable bacteria. Anaerobic (0% oxygen) conditions are then maintained in the vessel and the temperature is held at a constant value (typically 40 °C).

The produced biogas can be upgraded to natural gas (fossil) quality and injected into the gas grid or used as a vehicle fuel but is normally used on site to generate heat and electricity in a Combined Heat and Power-unit (CHP). The biogas yield depends on the composition of the feedstock and on the ambient conditions in the digester (e.g. temperature, retention time). It is possible that the same feedstock could have different gas yields. From one cubic meter biogas approximately 2 kWh electricity and 2 kWh heat can be produced depending on the CHP unit and gas Fact Sheet Upgrading Biogas to Biomethane composition (e.g. 55% CH₄ content in the biogas, 20 mega joule (MJ)/m³ , 38% electrical and thermal efficiency CHP unit).

The residue or digestate of the AD process can be separated into a liquid and fibrous fraction. The liquid can be returned to the land as a high value fertiliser and the solid fibre used as a soil conditioner. Fermentation improves the quality of manure as nutrients are more available for plants and pathogens and weed seeds are killed. Furthermore, as odours are broken down and neutralised during the fermentation process the development of odours during liquid manure storage and spreading is greatly reduced.

Organic products from industry which are used to produce biogas provide interesting agricultural opportunities. By using organic residues such as distiller's pulp, grease or food

wastes, the natural material cycles (carbon and nitrogen) is closed and provides a recirculation of the nutrients into agriculture. Biogas technologies contribute to environmental protection by releasing no carbon dioxide (CO₂) in comparison to fossil fuels. Energy from biogas is largely CO₂ neutral because the CO₂ released from burning biogas was already removed from the atmosphere through photosynthesis. The fermentation of manure also reduces emissions from methane, a gas that would have far more devastating effects on the climate than CO₂ if it escaped uncontrolled from raw liquid manure.

2.2 History and future trend of biogas

Historically, methane was discovered as flammable material for first time in 1776 in Europe by Alessandro Volta. Researchers make an effort to clear chemical structure of methane, the last formula was provided by Avogadro in 1821. After this detection, yield of methane (biogas) production gradually increased. In 1884 Louis Pasteur together with his student Gavon managed to produce 100 L methane from 1 m³ dung fermented at 35°C. Pasture experiment encourage production of biogas using deferent biomass for many purpose. For example gas from waste water treatment was used in 1897 to running on the street lamps of Exeter city. Also around (1930-1940) agricultural waste was used to produce biogas spicily in small city and town mainly in Europe.

Up to date stabilization of biogas plant is increasing in high rate in Europe due to legislation that supporting of biogas production figure (2.1). In other country such as China, India, Nepal, Vitamin production of biogas from small scale household biogas plant is highly spread. Palestine has high potential of biogas production due to high amount of available biomass [8]. Tareq Abu Hamed et al. (2011) estimate amount of biogas produces from different type of animal's excrete from house hold in Palestine depending on data in table (2.1) shown below [9]. Their result show that 330,000 kg per day of cattle manure and 100,000 kg of goat and sheep manure per day could produce 12,416 m³ of biogas per day. 10-20% of energy need for cooking in rural area could be covered with this amount of biogas.

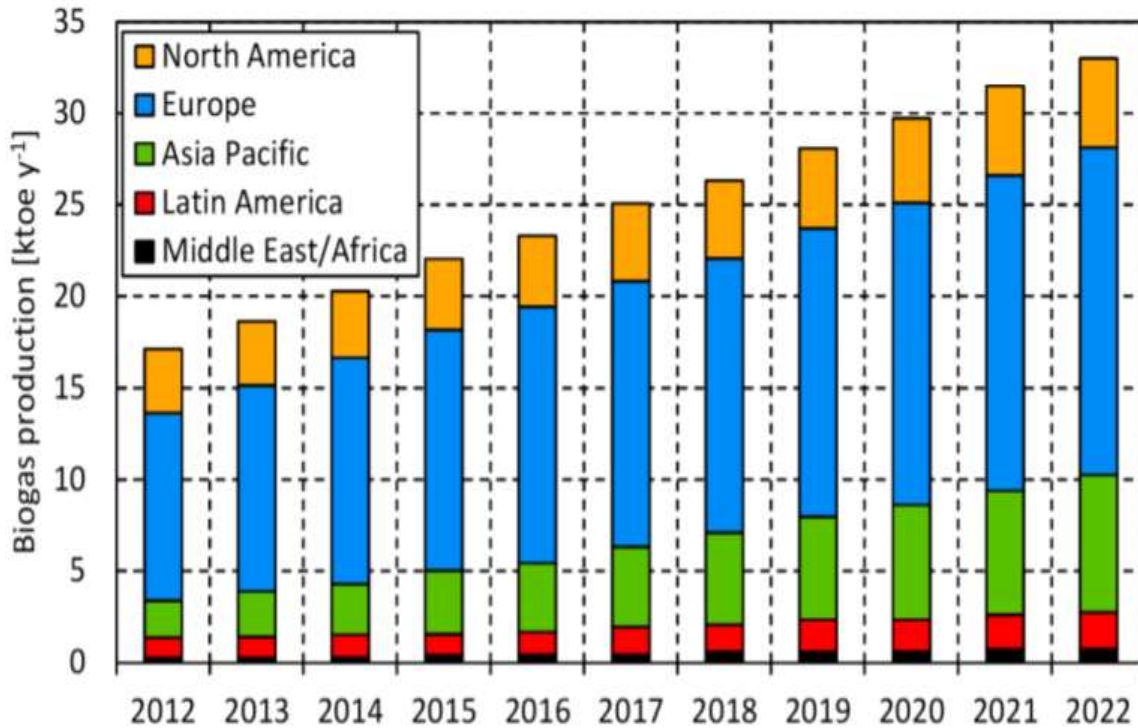


Figure 2.1: Biogas production at 2012 and trend to 2022 in different areas of the world [10].

2.3 Biochemical process of anaerobic digestion

Anaerobic digestion (AD) is complex linked processes in which obligatory and facultative bacteria tend to degrade organic material under anaerobic condition (in absence of oxygen) [11]. AD steps beginning with hydrolysis then acidogenesis, acetogenesis, methanogenesis shown figure (2.2) [12]. Degradation process produces three products; biogas with 70% methane and CO₂ 29%, wastewater and the nutrient-rich digestate which could be used as fertilizer [11, 13].

2.3.1 Hydrolysis

Hydrolysis is the first step in which AD facultative and obligatory microorganisms tend to convert insoluble complex organic material to soluble compounds (monomers) using specialized hydrolytic exoenzymes (hydrolase) as shown in equation (2.1) and equation (2.2) [11]. These enzymes are considered as biochemical catalysts that use water to cleave chemical bonds [14]. In such enzymatic reaction Carbohydrate (Polysaccharide), protein and fat (lipids)

degrade to monosaccharaides, amino acids, long chain fatty acids and glycerol respectively [11]. Hydrolysis of carbohydrate take place within a few hours, and hydrolysis of protein and lipids tack few days to decompose [11].special type of carbohydrate such as lignocellulose and lignin fibrous degraded only slowly and incomplete due to packing them tightly in lignin therefore difficult for bacteria to get at [11, 15].Hydrolysis process is the slowest reaction in overall anaerobic digestion.

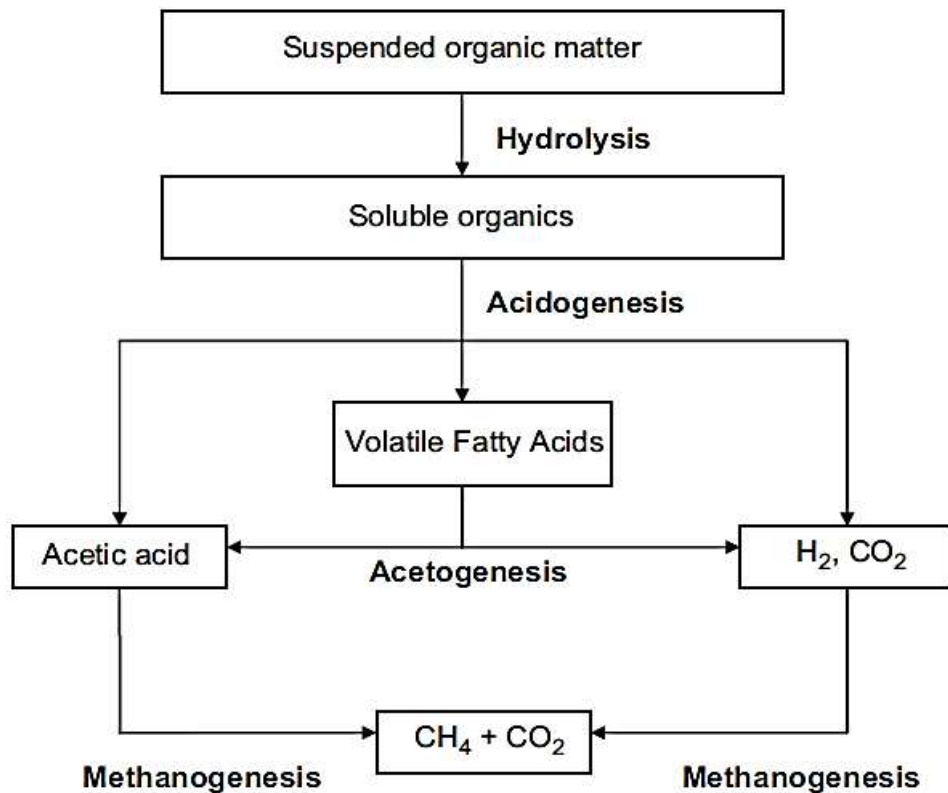
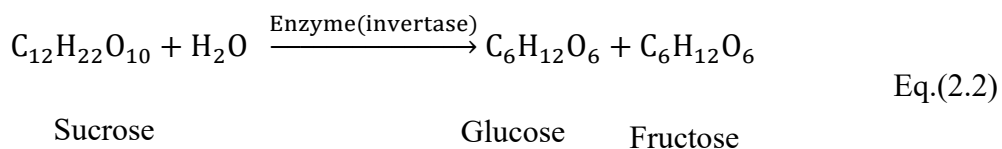
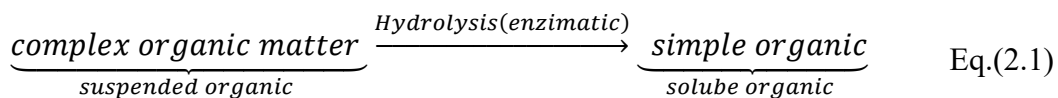


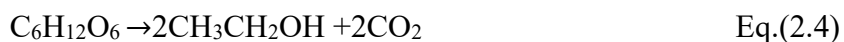
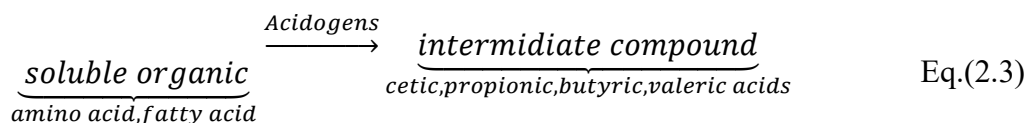
Figure 2.2: Subsequent steps in the anaerobic digestion process [12].

Thus it consider as overall rate-limiting step in AD. Sanders et al. (2000) show that at constant pH and temperature the key factor that control the hydrolysis rate is the amount of substrate surface available for hydrolysis[16]. In a larger surface and therefore an increase of hydrolysis rate (g/l/day) [16].



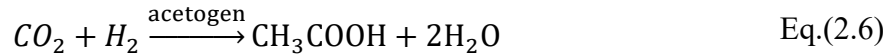
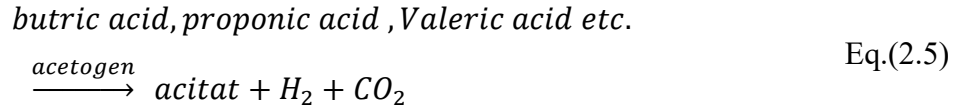
2.3.2 Acidogenesis

In this stage, the hydrolyzed compounds are fermented into volatile fatty acids (VFA) (acetic, propionic, butyric, valeric acids etc.), neutral compounds (ethanol, methanol), ammonia, and the pH falls as the levels of these compounds increases. Carbon dioxide and hydrogen are also evolved as a result of the catabolism of carbohydrates. The group of microorganisms responsible for this biological conversion is obligate anaerobes and facultative bacteria, which are often identified in the literature as acidogens. The specific concentrations of products formed in this stage vary with the type of bacteria as well as with culture conditions such as temperature and pH [17]. Typical reactions in the acid-forming stages are shown below in equation (2.3), glucose is converted to ethanol and carbon dioxide equation (2.4).



2.3.3 Acetogenesis

The third step is acidogenesis. Obligatory H₂ producers microorganisms (acetones microorganisms which have ability to produce acetate) further degraded VFA, alcohol, CO₂ and H₂ that produced in acetogenesis step to acetic acid equation (2.5) and equation (2.6). Other by-product such as CO₂, H₂ could be produced also.



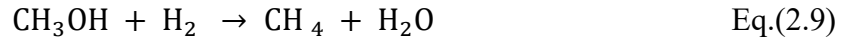
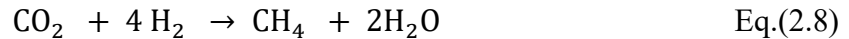
Partial pressure of hydrogen (H₂) in the system considered as specialized growth limitation to acetogenesis process. In each time that acetogen degrade molecule of butyric acid, proponic acid and valeric acid, hydrogen molecule will be produced [11]. with continuing the degradation process concentration (partial pressure) of H₂ would increase. Those microorganisms highly affected by high partial presser of H₂ where it can complete its metabolic process only under low H₂ pressure.

2.3.4 Mathanogenesis

The Last stage in anaerobic degradation of biomass is methanogenesis where methane production proceeded by obligatory anaerobic bacteria. The Substance acceptable to methanogen to produce methane would be classified to three category depend on their degradation path way and number of microorganisms that able to handle degradation process [11].

1. CO₂ type: CO₂, HCOO⁻, CO, all methanogen can reduce specie of this group.
2. Methyl type: CH₃OH, CH₃NH₃, (CH₃)₂NH⁺², (CH₃)₃NH⁺, CH₃SH, (CH₃)₂S, one type of methanogens can handle dismutation specie of this group.
3. Acetate type: CH₃COO⁻, many methanogens can oxide this group.

All methane-forming reactions have different methane yields equation (2.7), equation (2.8) and equation (2.9) show forming reaction from different type of compound. Nevertheless, Most of methane production comes from reduction of CO₂ type where it gives 70% of methane yield and only 27-30% from oxidation of acetate type[11].



Methanogens bacteria work in symbiotic with acetones to decrease partial pressure of H_2 . Methanogens can only live with high partial pressure of H_2 . Thus it tack produced hydrogen molecules in acetogenesis to complete its metabolic process [11].

2.4 Types of biogas plant

Classification of biogas plants depends upon the plants design and mode of working:

1. Batch type plant
2. Continuous type plant

2.4.1 Batch Type Biogas Plant

Batch type biogas plants are appropriate where daily supplies of raw waste materials are difficult to be obtained. A batch loaded digester is filled to capacity sealed and given sufficient retention time in the digester. After completion of the digestion, the residue is emptied and filled again. Gas production is uneven because bacterial digestion starts slowly, peaks and then tapers off with growing consumption of volatile solids.

This difficulty can overcome by having minimum two digesters so that at least one is always in operation. This problem can also minimize by connecting batch loaded digester in series and fed at different times so that adequate biogas is available for daily use. The salient features of batch-fed type biogas plants are:

1. Gas production in batch type is uneven.
2. Batch type plants may have several digesters for continuous supply of gas occupying more space.
3. This type of plants require large volume of digester, therefore, initial cost becomes high.

2.4.2 Continuous Type Biogas Plant

In continuous type biogas plant, the supply of the gas is continuous and the digester is fed with biomass regularly. Continuous biogas plants may be single stage, double stage or multiple stages. Digestion of waste materials in a single chamber or digester is called single stage process, in two chambers or digester is called multi stage process. In double stage process, acidogenic and methanogenic stage are physically separated into two chambers. These plants are economic, simple and easy to operate. These plants are generally for small and medium size biogas plants.

The important features of continuous type biogas plants are:

1. Gas production is continuous.
2. Retention period is less
3. Less problems as compared to batch type.
4. Small digestion chambers are required

2.5 Factors affecting AD process for biogas production

2.5.1 Temperature

Temperature condition could be classified to Thermophilic AD at (55–70°C) and mesophilic digestion at (37°C). Table (2.2) shows the advantage and disadvantage of thermophilic and mesophilic condition. Heat is produced from the energy generated by decomposition and microorganism, and the degradation of the material is faster when the temperature is between 35 and 37. If the temperature is less than 35, the process of decomposition will be very slow. And if increased, the microorganisms die.

Table 2.1: Advantage and disadvantage of thermophilic and mesophilic condition[18]

condition	Advantage	disadvantage
Thermophilic	faster reaction rates	acidification may occur , inhibiting biogas production
	higher-load bearing capacity	decreased stability
	higher productivity compared with Mesophilic	low-quality effluent
	-----	poor methanogenis
	-----	higher net energy input
	-----	increased toxicity of ammonia
	-----	more sensitive to environmental changes than mesophilic process
Mesophilic	better process stability and higher richness in bacteria	poor biodegradability
		low methane yields related to nutrient imbalance

2.5.2 PH

Anaerobic fermentation is divided into two stages: Acid production phase, Phase conversion of acids.

The acidity in the first stage is normal and the bacteria working at this stage are adapted (bacteria of decomposition and fermentation). The active bacteria in the second stage are methane bacteria, grow and work in a neutral medium where the pH is (6-8). The excess acidity in the digestion of biogas is the most common problem and can be treated in two ways:

Add alkaline chemicals to balance acidity such as: sodium carbonate, stop the feeding process temporarily until methane bacteria find enough time to reduce the amount of fatty acid [18].

Table 2.2: Optimum pH for process [18].

process	hydrolysis	Methanogenesis	acidogenesis
optimum pH	optimum hydrolytic enzyme activity at pH 6.0	most efficient at pH 6.5–8.2. optimal pH is 7.0	optimum pH between 5.5 and 6.5

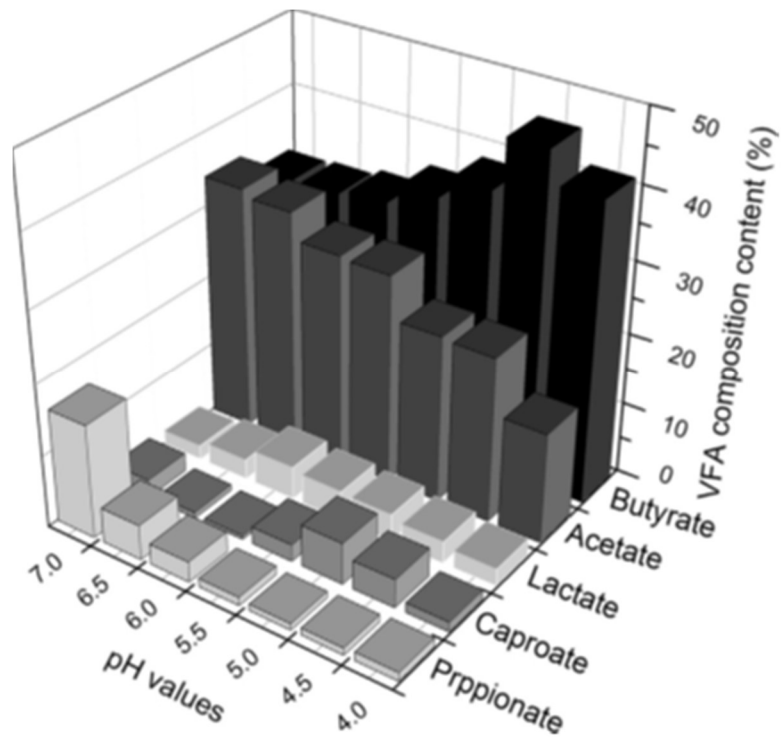


Figure 2.1:VFA composition based on carbon basis affected by pH [18].

2.5.3 C/N ration

One of the important indicators to know the possibility of producing biogas from a sample. The waste also vary in that, and the mixture is balanced by mixing nitrogen-rich residues with those rich in carbon. [18].

2.5.4 Organic Loading Rate (OLR)

The rate of feed depends on the type and nature of organic matter used, their degree of degradation, temperature, retention time, size of the digester, and the amount of gas to be produced.

The rate of gas production increases by increasing the feed rate according to the type of organic matter used. However, the efficiency of conversion of organic matter decreases if the rate of feeding exceeds a certain limit. Therefore, to achieve optimum feeding rate, two indicators should be observed: productivity gas efficiency and conversion efficiency [18].

2.5.5 Retention time

Is the time spent organic matter inside the digester tank, calculated in days in the case of animal and plant waste, and hours in the case of waste water as sewage. Retention time for common animal waste ranges from 30 to 45 days [18].

2.5.6 Moisture content

Usually moisture content have a positive impact on anaerobic digestion process [19]. Water is essential to methane fermentation as the nutrients for the microorganisms must dissolve in water before they can be assimilated [20]. The preferable moisture content is higher than 60% [14]. However, L. Márquez -Benavides et.al (2008) show that the methane production rate was higher at moisture content of 70% [21]. Water is important agent in bacterial movement, dissolving substance and diffusion of substrates to bacterial sites. high moisture contents may dilute carboxylic acid (such as acetic acid and amino acid) concentrations and provide for more mixing and aid in buffering reactions to reduce the pH inhibition [22].

Chapter three

Filter

3.1 Introduction

3.2 Cleaning of biogas

3.3 Raw Biogas Filtration

3.4 Chemical Filter design

3.5 Piping system

3.6 Valve system

3.7 Mechanical chemical Filter using water scrubber

3.8 Filter used in the project

3.1 Introduction

The conversion of biogas to biomethane will offer clear advantages and opportunities at some anaerobic digestion plants – both existing and proposed. The core of this guide is a review of the current readily available technologies that take raw biogas and enrich it to the point that it approaches pure methane – in order that it may be used in vehicles (as compressed natural gas) or injected into the natural gas grid. This introductory section discusses the circumstances where biomethane production may be appropriate. The most significant advantage in producing biomethane, as an alternative to the standard model of producing electricity and heat from a combined heat and power (CHP) unit, is one of efficiency of the energy production process. Where all or most of the heat from the CHP unit is effectively utilised then the argument for biomethane production is significantly reduced, because the efficiency of use of the energy in the biogas is high. Where little or none of the heat from the CHP unit is used to good effect (apart from the sacrificial heat load on the digester) then the efficiency of energy conversion will be only between 30 and 40%. By comparison, most modern natural gas appliances have very high efficiencies.

Upgrading Biogas to Biomethane Biogas upgrading, or “sweetening,” is a process whereby most of the CO₂, water, H₂S, and other impurities are removed from raw biogas. Because of its highly corrosive nature and unpleasant odor, H₂S is typically removed first, even though some technologies allow for concurrent removal of H₂S and CO₂. The following sections discuss various removal technologies with specific emphasis on those technologies most suitable for our project.

3.2 Cleaning of biogas

Apart from methane and carbon dioxide, biogas can also contain water, hydrogen sulphide, nitrogen, oxygen, ammonia, siloxanes and particles. The concentrations of these impurities are dependent on the composition of the substrate from which the gas was produced. In those upgrading technologies where carbon dioxide is separated from the biogas, some of the other unwanted compounds are also separated. However, to prevent corrosion and

mechanical wear of the upgrading equipment itself, it can be advantageous to clean the gas before the upgrading.

3.3 Raw Biogas Filtration

3.3.1 Particle Removal

Biogas contains small solid particles, foams, greases and other contaminants that can damage engines by causing clogging or blocking of downstream equipment increasing maintenance costs and downtime. Particulates can be present in biogas and landfill gas and can cause mechanical wear in gas engines and gas turbines. Particulates that are present in the biogas are separated by mechanical filters, in this project we will use sand to remove this substance.

3.3.2 Removal of water vapor

When leaving the digester, biogas is saturated with water vapour , and this water may condensate in gas pipelines and cause corrosion. Water can be removed by cooling, absorption. By increasing the pressure or decreasing the temperature, water will condensate from the biogas and can thereby be removed. Water can also be removed by using wire mesh scrubber or silica gel inside the filter.

- **The major benefits to Remove Water from Biogas**

1. Increases Efficiency (or Energy Output) of Engine
2. Prevents Corrosion of Pipework and Components
3. Partial Removal of H₂S, Ammonia, Siloxanes and other water soluble contaminants
4. Reduces Contamination of Engine Oil
5. Increase Service Life of Activated Carbon.

3.3.3 Siloxane removal

Siloxanes are compounds containing a silicon-oxygen bond. They are used in products such as deodorants and shampoos, and can therefore be found in biogas from sewage sludge

treatment plants and in landfill gas. When siloxanes are burned, silicon oxide, a white powder, is formed which can create a problem in gas engines, so we will use sand, water or cooling the gas to remove this substance.

3.3.4 Removal of hydrogen sulphide

3.3.4.1 Water scrubbing

In the hydrogen sulfide removal process, the H₂S is initially physically absorbed into the adsorbed water undergoing the dissociation according to following reactions:[23]

3.3.4.2 Iron oxide reaction

Hydrogen sulfide reacts readily with either iron oxide or iron chloride to form insoluble iron sulfide. The reaction can be exploited by adding the iron chloride to the digester feed material or passing the biogas through a bed of iron oxide-containing material. The iron oxide comes in different forms such as rusty steel wool, iron oxide pellets or wood pellets coated with iron oxide. The iron oxide media needs to be replaced periodically. The regeneration process is highly exothermic and must be controlled to avoid problems.[24]

143g H₂S /Kg Iron oxide (absorbent) [25]

Density of absorbent is 1.2 Kg/l [26]

- **Description of material:**

Iron oxides and oxide-hydroxides are widespread in nature, play an important role in many geological and biological processes, and are widely used by humans, e.g., as iron ores, pigments, catalysts, in thermite and hemoglobin.

3.3.4.3 Activated carbon

Activated carbon impregnated with potassium iodide can catalytically react with oxygen and H₂S to form water and sulfur. The reaction is best achieved at 7 to 8 bar (unit of pressure) and 50 to 70 C. Activated carbon beds also need regeneration or replacement when saturated.[24]

3.3.4.4 Hydrogen Sulfide scrubber

All biogas is vacuumed through a H₂S filter consisting of a commercialized scrubber made of iron oxide; biogas enters containing more than 500 ppm and leaves with less than 1 ppm H₂S. It's estimated that the H₂S filter, may last more than 5 years with no maintenance.[24]

3.3.5 Removal of nitrogen

Nitrogen may be removed by liquefying the methane fraction of biogas by mechanical refrigeration, leaving the other gas fractions to be exhausted. Considerable refrigeration equipment is required for this process and it is usually prohibitively costly. The best practice is to avoid drawing air into the treatment system to the greatest extent possible, thereby minimizing the nitrogen content.[27]

3.3.6 Removal of ammonia

Activated carbon, silica gel or a slightly acidic solution can be used. When the ammonia passes through this solution it will be dissolved.

Silica gel Description

Silica gel is a granular material, with a glassy luster, a porous form of silicon dioxide that artificially creates sodium silicate, it is tough and harsh and highly absorbent substance for moisture, with high acidity.

Absorbtion degree of silica gel is : 100 g NH₃/Kg silica gel [28]

Density of silica gel= 673 Kg/L [26]

3.3.7 Co2 removal

The CO₂ can be scrubbed by water, activated carbon, charcoal and soda lime.

- **Soda lime Description**

Soda lime is a mixture of chemicals, used in granular form in closed breathing environments, such as general anaesthesia, submarines, rebreathers and recompression chambers, to remove carbon dioxide from breathing gases to prevent CO₂ retention and carbon dioxide poisoning.[29,30]

100g of soda lime can absorb approximately 26L CO₂ [31]

Density of soda lime= 2.52×10^{-3} Kg/l [33]

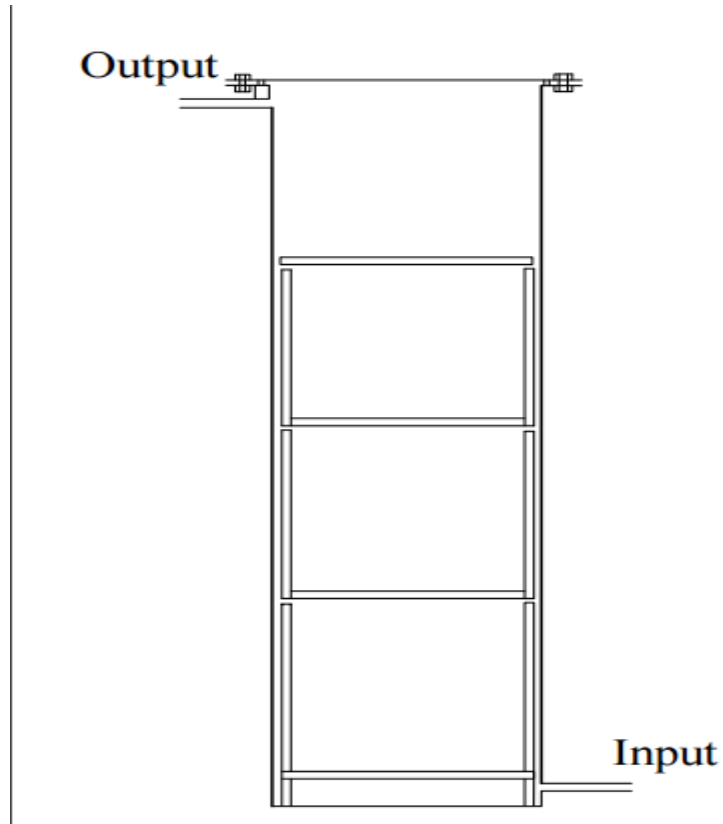
Density of CO₂= 1.9 Kg/m³ [32]

- **The main components of soda lime are**

1. Calcium hydroxide, Ca(OH)₂ (about 75%)
2. Water, H₂O (about 20%)
3. Sodium hydroxide, NaOH (about 3%)
4. Potassium hydroxide, KOH (about 1%). [33]

3.4 Chemical Filter design

In figure 3.1 show the section of filter :



Figures 3.1:Section of filter design

In our project, we choose this filter because of:

1. High efficiency system
2. Low pressure drop design
3. Vertical installation
4. High performance

3.4.1 Equation of filter design

1. Calculation of cross section

height of the layer is ()cm (assumed)

Flow is ()m³biogas/h (assumed)

$$\frac{\frac{\text{m}^3\text{gas}}{\text{hour}} \text{ throughput} \times 1000 \times 1000}{3600} = \text{cm}^3\text{gas/s (throughput)} \quad \text{Eq.(3.1)}$$

The maximum flow rate velocity in the chamber is () cm/s (assumed)

- The area of the section is then

$$\frac{\text{flow rate} \frac{\text{cm}^3\text{gas}}{\text{s}} \text{ throughput}}{\text{flow rate velocity} \frac{\text{cm}}{\text{s}}} = \text{cross section of champer (cm}^2\text{)} \quad \text{Eq.(3.2)}$$

$$\text{Divide by 10000} = \text{cross section (m}^2\text{)} \quad \text{Eq.(3.3)}$$

- Radius of a chamber :-

$$\sqrt{\text{cross section area}/\pi} = \text{radius (m)} \quad \text{Eq.(3.4)}$$

2. Calculation of the height of the chamber

- The actual values depend on the absorbent used

1. Density () kg/liter
2. absorption degree () g material to be removed/kg absorbent

Flow : () m³ biogas per day

Quantity of material to be removed from gas : () g material to be removed/m³ gas (estimate)

() number of operating days desired between absorbent exchange

- Quantity of material to be removed from gas per operating period

() m³ biogas per day × () g material to be removed/m³ gas × () operating days =
() g material to be removed/operating period

Eq.(3.5)

- Quantity of absorbent in Kg per operating period

$$\frac{(\text{) g material to be removed/operating period}}{(\text{) g material to be removed/kg absorbent}} = (\text{) Kg absorbent/operating period}$$

Eq.(3.6)

- Quantity of absorbent in Liter per operating period

$$\frac{(\text{) kg absorbent/operating period until exchange}}{\text{Density } (\text{) kg/L}} = (\text{) liter absorbent/operation period}$$

Eq.(3.7)

- Percent of dead volume from chamber volume

addition for dead volume (base , head and intermediate layers) =

() % from chamber volume (estimate)

Eq.(3.8)

- Dead volume addition

dead volume % × Quantity of absorbent = dead volume addition

Eq.(3.9)

- Chamber volume in liter or meter cubic

Quantity of absorbent + dead volume addition = Chamber volume

Eq.(3.10)

- Chamber height in meter

$$\frac{\text{volume(m}^3\text{)}}{\text{cross section(m}^2\text{)}} = \text{chamber height(m)}$$

Eq.(3.11)

- Number on intermediate layers

Number of intermediate layers = height/dead volume

Eq.(3.12)

3.4.2 Calculations of filter design

3.4.2.1 Calculation for H₂S

1. Calculation of cross section

height of the layer is 25 cm (assumed)

Flow is 1.25 m³biogas/h (assumed)

$$\frac{1.25 \frac{\text{m}^3 \text{gas}}{\text{hour}} \text{ throughput} \times 1000 \times 1000}{3600} = 347.2 \text{ cm}^3 \text{gas/s (throughput)}$$

From eq.(3.1)

The maximum flow rate velocity in the chamber is 0.5 cm/s (assumed)

- The area of the section is then

$$\frac{347.2 \frac{\text{cm}^3 \text{ gas}}{\text{s}} \text{ throughput}}{0.5 \frac{\text{cm}}{\text{s}} \text{ flow speed}} = 695 \text{ cm}^2 \text{ cross section of chamber}$$

From eq.(3.2)

$$\text{Divide by } 10000 = 0.0695 \text{ m}^2 \text{ cross section}$$

From eq.(3.3)

- Radius of a chamber :-

$$\sqrt{695/\pi} = 14.8 \text{ cm}$$

From eq.(3.4)

2. Calculation of the height of the chamber

- The actual values depend on the absorbent used

1. Density = 1.2 kg/liter

2. absorption degree = 143g H₂S/kg iron oxide

Flow = 30 m³ biogas per day

Quantity of material to be removed from gas = 3.5 g H₂S/m³ gas (estimate)

operating days = 60 days desired between absorbent exchange

- Quantity of material to be removed from gas per operating period

$$30 \text{ m}^3 \text{ biogas per day} \times 3.5 \text{ g H}_2\text{S/m}^3 \text{ gas} \times 60 \text{ operating days} = 6300 \text{ g H}_2\text{S /operating period}$$

From eq.(3.5)

- Quantity of absorbent in Kg per operating period

$$\frac{6300 \text{ g H}_2\text{S /operating period}}{143 \text{g H}_2\text{S/kg iron oxide}} = 44 \text{ Kg iron oxide/operating period until exchange}$$

From eq.(3.6)

- Quantity of absorbent in Liter per operating period

$$\frac{44 \text{ kg iron oxide/operating period until exchange}}{1.2 \text{ Kg/L}} = 36.6 \frac{\text{liter iron oxide}}{\text{operation period}}$$

From eq.(3.7)

- Percent of dead volume from chamber volume

addition for dead volume (base , head and intermediate layers) =
25 %from chamber volume(estimate)

From eq.(3.8)

- Dead volume addition

$$0.25 \text{ dead valume} \times 36.6 \text{ liter iron oxide/operating period} = 9.15 \text{ dead volume addition}$$

From eq.(3.9)

- Chamber volume in liter or meter cubic

$$36.6 \text{ liter iron oxide/operating period} + 9.15 \text{ dead volume addition} = \\ 45.75 \text{ chamber volume in L or } 0.04575 \text{ m}^3$$

From eq.(3.10)

- Chamber height in meter

$$\frac{0.04575(\text{m}^3)}{0.0695 (\text{m}^2)} = 0.65 (\text{m})$$

From eq.(3.11)

- Number on intermediate layers

$$\text{Number of intermediate layers} = (0.65/0.25) = 3 \text{ layers} \quad \text{From eq.(3.12)}$$

3.4.2.2 Calculation for NH₃

1. Calculation of cross section

height of the layer is 25 cm (assumed)

Flow is 1.25 m³biogas/h (assumed)

$$\frac{1.25 \frac{\text{m}^3 \text{gas}}{\text{hour}} \text{ throughput} \times 1000 \times 1000}{3600} = 347.2 \text{ cm}^3 \text{gas/s} \quad (\text{throughput})$$

From eq.(3.1)

The maximum flow rate velocity in the chamber is 0.5 cm/s (assumed)

- The area of the section is then

$$\frac{347.2 \frac{\text{cm}^3 \text{gas}}{\text{s}} \text{ throughput}}{0.5 \frac{\text{cm}}{\text{s}} \text{ flow speed}} = 695 \text{ cm}^2 \text{ cross section of chamber}$$

From eq.(3.2)

$$\text{Divide by 10000} = 0.0695 \text{ m}^2 \text{ cross section} \quad \text{From eq.(3.3)}$$

- Radius of a chamber :-

$$\sqrt{695/\pi} = 14.8 \text{ cm} \quad \text{From eq.(3.4)}$$

2. Calculation of the height of the chamber

- The actual values depend on the absorbent used

1. Density = 673 kg/liter

2. absorption degree = 100g NH₃/kg Silica gel

Flow = 30 m³ biogas per day

Quantity of material to be removed from gas = 3 g NH₃/m³ gas (estimate)

operating days = 60 days desired between absorbent exchange

- Quantity of material to be removed from gas per operating period

$$30 \text{ m}^3 \text{ biogas per day} \times 3 \text{ g NH}_3/\text{m}^3 \text{ gas} \times 60 \text{ operating days} = 5400 \text{ g NH}_3/\text{operating period}$$

From eq.(3.5)

- Quantity of absorbent in Kg per operating period

$$\frac{5400 \text{ g NH}_3/\text{operating period}}{100 \frac{\text{g NH}_3}{\text{kg silica gel}}} = 54 \text{ Kg} \frac{\text{silica gel}}{\text{operating period until exchange}}$$

From eq.(3.6)

- Quantity of absorbent in Liter per operating period

$$\frac{54 \text{ kg silica gel/operating period until exchange}}{673 \text{ Kg/L}} = 0.08 \frac{\text{liter silica gel}}{\text{operation period}}$$

From eq.(3.7)

- Percent of dead volume from chamber volume

addition for dead volume (base , head and intermediate layers) =
25 %from chamber volume(estimate)

From eq.(3.8)

- Dead volume addition

0.25 dead valume × 0.08 liter silica gel/operating period = 0.02 dead volume addition

From eq.(3.9)

- Chamber volume in liter or meter cubic

0.08 liter silica gel/operating period + 0.02 dead volume addition =
0.1 chamber volume in L or 0.0001 m³

From eq.(3.10)

- Chamber height in meter

$$\frac{0.0001(\text{m}^3)}{0.0695 (\text{m}^2)} = 0.001 (\text{m})$$

From eq.(3.11)

- Number on intermediate layers

Number of intermediate layers = (0.001/0.25) = 0.005 layer From eq.(3.12)

We can assumed number of layer that calculated by 1 layer with lower layer depth.

3.4.2.3 Calculation for CO₂

1. Calculation of cross section

height of the layer is 25 cm (assumed)

Flow is 1.25 m³biogas/h (assumed)

$$\frac{1.25 \frac{\text{m}^3 \text{gas}}{\text{hour}} \text{ throughput} \times 1000 \times 1000}{3600} = 347.2 \text{ cm}^3 \text{gas/s} \quad (\text{throughput})$$

From eq.(3.1)

The maximum flow rate velocity in the chamber is 0.5 cm/s (assumed)

- The area of the section is then

$$\frac{347.2 \frac{\text{cm}^3 \text{gas}}{\text{s}} \text{ throughput}}{0.5 \frac{\text{cm}}{\text{s}} \text{ flow speed}} = 695 \text{ cm}^2 \text{ cross section of chamber}$$

From eq.(3.2)

$$\text{Divide by } 10000 = 0.0695 \text{ m}^2 \text{ cross section}$$

From eq.(3.3)

- Radius of a chamber :-

$$\sqrt{695/\pi} = 14.8 \text{ cm}$$

From eq.(3.4)

2. Calculation of the height of the chamber

- The actual values depend on the absorbent used

1. Density = 2.52 kg/liter

2. absorption degree = 49.4g CO₂/0.1 kg Soda lime

Flow = 30 m³ biogas per day

Quantity of material to be removed from gas = 35 g CO₂/m³ gas (estimate)

operating days = 60 days desired between absorbent exchange

- Quantity of material to be removed from gas per operating period

$$30 \text{ m}^3 \text{ biogas per day} \times 35 \text{ g CO}_2/\text{m}^3 \text{ gas} \times 60 \text{ operating days} = 63000 \text{ g CO}_2/\text{operating period}$$

From eq.(3.5)

- Quantity of absorbent in Kg per operating period

$$\frac{63000 \text{ g CO}_2/\text{operating period}}{49.4 \frac{\text{g CO}_2}{0.1 \text{ kg soda lime}}} = 127 \text{ Kg} \frac{\text{soda lime}}{\text{operating period until exchange}}$$

From eq.(3.6)

- Quantity of absorbent in Liter per operating period

$$\frac{127 \text{ kg soda lime /operating period until exchange}}{2.52 \text{ Kg/L}} = 50 \frac{\text{liter soda lime}}{\text{operation period}}$$

From eq.(3.7)

- Percent of dead volume from chamber volume

$$\text{addition for dead volume (base , head and intermediate layers)} = 25 \% \text{ from chamber volume (estimate)}$$

From eq.(3.8)

- Dead volume addition

$$0.25 \text{ dead volume} \times 50 \text{ liter soda lime/operating period} = 12.5 \text{ dead volume addition}$$

From eq.(3.9)

- Chamber volume in liter or meter cubic

$$50 \text{ liter soda lime/operating period} + 12.5 \text{ dead volume addition} = 62.5 \text{ chamber volume in L or } 0.0625 \text{ m}^3$$

From eq.(3.10)

- Chamber height in meter

$$\frac{0.0625(\text{m}^3)}{0.0695 (\text{m}^2)} = 0.8 (\text{m})$$

From eq.(3.11)

- Number on intermediate layers

$$\text{Number of intermediate layers} = (0.8/0.25) = 3 \text{ layers}$$

From eq.(3.12)

3.5 Piping system

3.5.1 Design and operating

The design pressure used for determination of pipe and valve wall thickness schedules should be computed as follows: [34, 35]

$$\text{Design pressure} = 1.5 * \text{Maximum Operating Pressur} \quad \text{Eq.(3.13)}$$

High pressure systems should be hydrostatically tested to assure that there are no safety problems with the system. The pressure at which the system should be hydrostatically tested is computed as follows:[36]

$$\text{Hydrostatic Test Pressure} = 1.5 * \text{Design Pressure} \quad \text{Eq.(3.14)}$$

3.5.2 Pipe sizing

A quick determination of pipe size can be made using the diagram presented in Figure (3.2). In order to use the figure, the rate of gas flow in cubic feet per hour and the length of pipe must be determined.

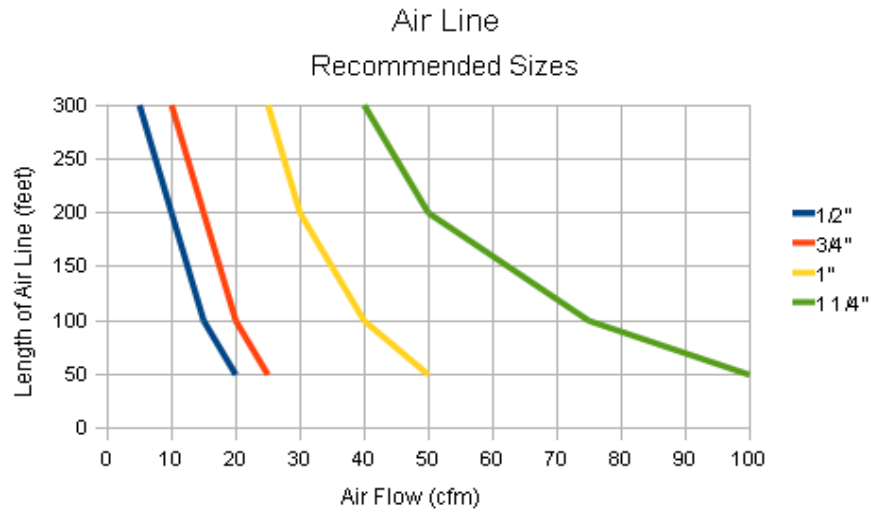


Figure 3.2: Pipe selection diagram [35]

Table 3.1: Piping material [35]

Material	Advantages	Disadvantages
Plastic	Easy to work, inexpensive	Subject to breaking, can be eaten by rodents valves more expensive; than galvanized, also subject to ultraviolet degradation
Galvanized Iron	Less breakable	Can rust, pipe more expensive than plastic
Flexible (5 ply rubber hose)	Ease of connection to equipment	Expensive

3.6 Valve System

A summary of the advantages and disadvantages of the different types of valves that can be used in biogas system is presented in Table (3.2) valve material selection is subject to the same restrictions as piping system. Brass ball valves (brass taps) can be used; but, these must not contain any lead as hydrogen sulfide tends to attack the lead and destroy the tap.

Table 3.2: Valve types [35]

Valve type	Advantages	Disadvantages
Gate	Low cost	Moisture can be trapped in slot
Globe	Slightly higher cost than gate	Not good for quick shut-off
Butterfly	Low cost	Not recommended for combustible gas service
ball	Best choice for shut-off	Cost

3.7 Mechanical chemical Filter using water scrubber

In this filter we have :

1. Packing provides the large interface area for the contact of liquid and gas phase inside the packed tower.
2. open structure: low resistance to gas flow
3. Promote uniform liquid distribution on the packing surface.
4. Promote uniform vapor gas flow across the column cross section.

And we will put iron wool to partially absorbed of H_2S , to create a gas obstruction and make better contact between gas and water .

3.7.1 The working principle of the filter

The scrubbing process as being counter current with the biogas coming in from the side of the tank and going out from the top of the tower while the water is introduced from the top of the scrubber and the flows out from the bottom of the tower.

The scrubbing setup consists of the water scrubber with an iron wool packed bed connected to a 800 liter tank containing pure water with the aid of a piping network that consists of a half inch pipe, 1 inches and 1/2 inch nipples and a 1 inch elbow, Teflon tapes were used to tighten the internal and external threading in the pipe and pipe fittings and 1/2 inch nipples for gas at outlet of digester, inlet and outlet of the first filter, inlet and outlet of the second filter that consist of silica gel (to remove ammonia and water vapor) and sodium polyacrylate (because it has ability to absorb as much as 200 to 300 times its mass in water) . The iron wool packed bed was used to enhance the contact time (interfacial area) between the biogas and water, and also to react with the hydrogen sulphide in the biogas. Pressurized water was also sprayed from top with the aid of a shower sprayer to absorb the CO_2 and H_2S from pressurized biogas. The movement of the biogas was achieved by means of upward displacement, downward delivery elemental technique. Purified biogas was then collected into a tube where it was stored for further analysis .The design of mechanical chemical filter shown in figure (3.3).

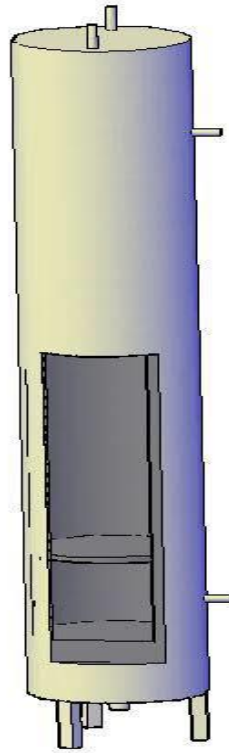


Figure 3.3: The design of mechanical chemical filter

3.7.2 The solubility of important composition of biogas in water

The other reason to choose this filter is the high solubility of harmful composition of biogas , and there is a comparison between the solubility of composition of biogas :

3.7.2.1 The solubility of methane in water

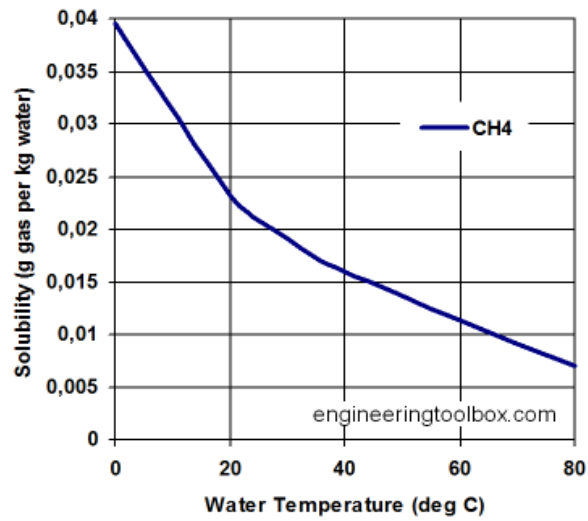


Figure 3.4: solubility of methane in water [37]

3.7.2.2 The solubility of carbon dioxide in water

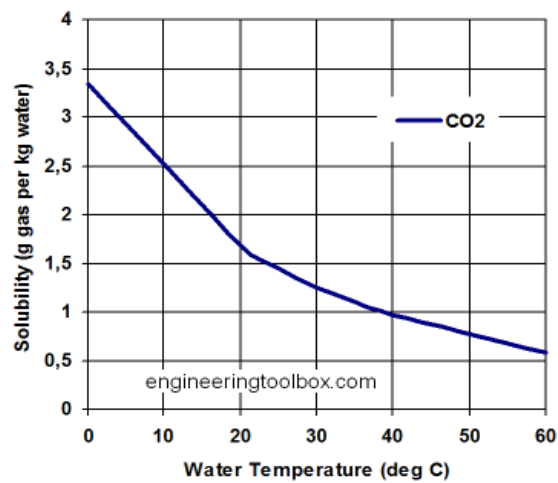


Figure 3.5: solubility carbon dioxide in water [37]

3.7.2.3 The solubility of hydrogen sulphide in water

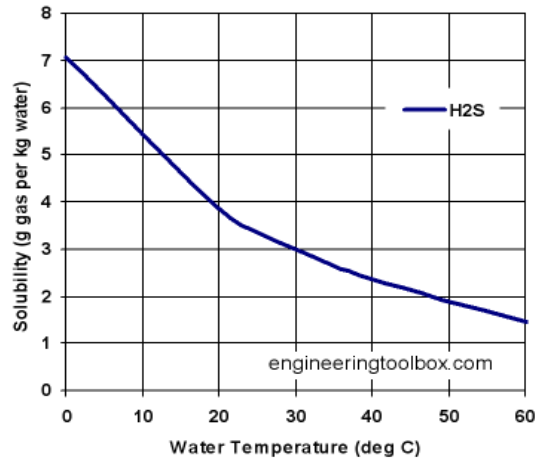


Figure 3.6: solubility of hydrogen sulphide in water [37]

3.7.3 Design of the mechanical chemical biogas filter

We will use filtration by scrubber , The design of filter by water scrubber involves the following steps:

1. Assumptions of basic data.
2. Solubility data generation.
3. Material balance and determination of water flow rate.
4. Selection of packing material.
5. Determination of column diameter.
6. Determination of the height of the packed bed column.
7. Selection of packing support and water distributor

3.7.3.1 Assumptions of basic data

The basic data assumed during the design of the scrubber were:

1. Inlet pressure of the biogas = 100 kPa
2. Inlet temperature of biogas = 25 °C
3. Volume of Biogas to be Scrubbed= 0.050 m³
4. Percentage of carbon dioxide in biogas = 35%

5. Partial pressure of CO₂ = 0.35 kPa

3.7.3.2 Solubility data generation

Henry's Law was used to determine the solubility of CO₂ in water. Solubility of CO₂ in water at 1 bar and 298K is given as 2857 Pa.m³/mol

Henry's Law:

$$P_t = K_H * C_{\max} \quad (1) \quad \text{Eq.(3.13)}$$

C_{\max} = Saturation concentration of CO₂ in mol/m³

K_H = Henry's coefficient [Pa.m³/mol] = 2857 Pa.m³/mol

P_t = Partial pressure of CO₂ component in biogas (Pa)

This equation is used to determine Henry's law constant for methane, and gives us guidance on melting methane in water.

3.7.3.3 Material balance and determination of water flow rate

$$P_{A1} - P_{A2} = \frac{F_1 \pi}{F_G C_T} (C_{A1} - C_{A2}) \quad \text{Eq.(3.14)}$$

$$\frac{F_1}{F_G} = 10 \quad \text{Eq.(3.15)}$$

Equations (3.14) and (3.15) were used in calculating the pressure drop in the scrubber with known parameters like the ratio of molar flow rate of water to biogas, molar density of water, total pressure and difference in concentration of biogas at inlet and outlet.

Ergun Equation:

$$\Delta P = \frac{150 \mu (1-\varepsilon) 2V_S L}{\varepsilon^3 D_p^2} + \frac{1.75 (1-\varepsilon) \rho V_S^2}{\varepsilon^3 D_p} \quad \text{Eq.(3.16)}$$

Equation (3.16) was used in determining the superficial velocity of carbon dioxide using parameters such as gas density, void fraction, equivalent spherical diameter of packing, dynamic viscosity of the gas, length of the packed bed and pressure drop.

Flow rate equation:

$$Q = V_S A \quad \text{Eq.(3.17)}$$

Equation (3.17) was used in verifying the Area of the reacting column using the calculated superficial velocity and the molar flow rate of the gas.

3.7.3.4 Determination of volume, height and diameter of filter:

$$\text{Volume of a cylinder} = AH \quad \text{Eq.(3.18)}$$

$$V_V = hA_{CS} \frac{F_G}{\pi \alpha K_G} (P_{A1} - P_{A2}) \quad \text{Eq.(3.19)}$$

With a specified volume and a known area, the height of the packed bed was also established using equation (3.19).

3.7.3.5 Selection of packing material:

A packing material used in enhancing the contact time (interfacial area) between the gas and water. The packing material selected for the scrubber was iron wool with the following specifications:

Equivalent spherical diameter of packing=5×10⁻³m

Void fraction=0.5

Iron wool was selected because it removes hydrogen sulphide from biogas

3.7.3.6 Selection of packing support and water distributor

Metal sieves were placed at the top and bottom of the middle section of the scrubber to act as support for the iron wool packing. Water was supplied to the scrubbing tower by means of a connected overhead 800 liters tank and the water was distributed by means of a water sprayer connected to the top section of the scrubber.

3.7.4 Design Specifications

Using the Material/ mass balance equation, the Ergun equation, the flow rate equation, the relationship between volume, area and height of a packed bed; the following design specifications of the mechanical chemical filter were obtained:

gas velocity 0.96 m/s , height of packed bed 140 cm , radius of packed bed 25 cm , radius of second filter 7 cm and height of second filter 40 cm.

Type of material : stainless steel schedule 40.

3.8 Filter used in the project

We choice the mechanical chemical filter that shown in the figure (3.8) below. Because of lack of chemicals to be used in the chemical filter , high cost of chemicals , decrease the number of filters and easy of mechanical chemical filter design.



Figure 3.7: Filter used in the project

Chapter four

Results and Discussion

4.1 Results

4.2 Conclusion

4.3 Recommendations

4.1 Results

Table 4.1 represent the composition of raw biogas (pre- scrubbed) and composition of purified biogas (scrubbed). The table show that there is an increase in methane content from 58.5% to (80-82.1)%, due to removal of Carbon dioxide, Hydrogen Sulphide and Oxygen. Carbon dioxide was reduced from 44.4% to (14-18.8)%, Hydrogen Sulphide was reduced from 0.12% to (0.005-0.0053)% while Oxygen increase from 0.4% to 1.3% .

Table 4.1: Percentage of gases before and after filtration

	Percentages of gases before filtration	Percentages of gases after filtration
Methane	58.5%	(80-82.1)%
Carbon dioxide	44.4%	(14-18.8)%
Hydrogen sulphide	0.12%	(0.005-0.0057)%
Oxygen	0.4%	(0.9-1.3)%

4.2 Conclusion

It has been found that the filter achieves 82.1% of pure methane and greatly reduces carbon dioxide and hydrogen sulfide, which in turn makes it suitable for maximizing the generation of electricity and fuel. This shows that the purification of biogas by a mechanical chemical filter is very effective in removing carbon dioxide and hydrogen sulfide.

4.3 Recommendations

After completing this project and observing the results we recommend some recommendations that would rise the efficiency of pure methane production :

1. Should make recirculation of water from outlet to the tank .
2. Increase the number of layers inside the mechanical filter to rise the efficiency of purification.
3. Add a chemical material to reduce the percentage of carbon dioxide.

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