CHAPTER ONE

INTRODUCTION

1.1 Background

Energy plays a central role in addressing the two great challenges; fighting poverty and addressing climate change. Energy is basic to fulfill all human needs it enables for greater productivity, prosperity and comfort. Access to energy to empower the citizens of the country particularly the disadvantaged and unserved people most of them living in the rural and remote areas is therefore essential and should be part of any vision document of inclusive growth and for achieving the UN millennium development goals.

As we all know identified fossil fuel reserves are finite and limited. Moreover energy generation from the sources using conventional technologies adversely affects the environment. In recent years there is a paradigm shift and global thinking and developing renewable energy strategy which is considered as an important component of any countries energy planning process. Solar, wind, and hydropower are the most common renewable energies which come to mind. But there is another source of renewable energy in abundance all around us yet it's mostly our owned. It's energy generation from waste.

Generation of energy in the form of biogas from bio degradable organic waste is a commercially proven option for enhancing renewable energy in urban, rural and industrial areas. One of the advantages of this biogas is that it can be generated during day and night and can be stored in balloons to be utilized when the user wants to use. biodegradable Organic waste include animal manure, poultry droppings, vegetable and food's waste, food processing waste, affluence generated from rurally units which are generally disposed of either untreated or with some treatments . All these can be used as a resource for generation of biogas. Anaerobic digestion or bio-methanation is a process by which biodegradable organic materials are microbiologically converted into biogas under anaerobic conditions. in other words it is a biological process carried out by a set of bacteria in the absence of oxygen during the process complex organic solids are converted to biogas and bio-manual; the biogas that is produced mainly consists of methane which is about 60% and carbon dioxide which is about 35% and they have small amounts of hydrogen sulphide and moisture.

Raw biogas can be directly burned and used in engines whose calorific value varies from 3000 to 4200 kilocalories per meter cube raw biogas can be purified easily for better combustion with the help of scrubbers; the scrubbers remove hydrogen sulfide and carbon dioxide from the raw biogas. Removal of carbon dioxide from biogas is an optional issue; if we which to have high calorific value biogas carbon dioxide scrubber would be helpful. Otherwise carbon dioxide scrubber is not necessary. Small size biogas plants don't keep carbon dioxide scrubbers to keep the project cost low. Raw biogas with methane contains of about 95% can be compressed and bottled in cylinders. Compressed biogas is called compressed biogas or CBG and it is same as compressed natural gas CNG in terms of calorific value and quality of gas. The biogas burns with clean and sootless flame. The biogas can be utilized directly as fuel for thermal applications meaning heating or cooking or can be used to run engine generator set for production of mechanical or electrical power. Thus adoption of anaerobic technology which is environmentally one of the most benign technologies generates valuable renewable energy and also renders waste suitable for application as a rich source of organic manure. This process not only reduces the quantity of waste but also improves their quality to meet required pollution control standards. the other benefits include improved quality of environment air and water both at the local and Global levels better Health in sanitation improved quality of life in urban and rural areas.

1.2 Problem Statement

The electrical power consumption had grown larger due to the large population and growth of the industrial section which requires more power hence more fuel consumption on the other hand the pollution is getting larger so it's necessary to find an alternative source which is renewable and environment friendly.

1.3 Objectives

1- Possibility of using biogas as a fuel for diesel generator.
2- To reduce diesel consumption.
3- To reduce the harmful exhaust gases emissions.

1.4 Methodology

1- To modify diesel engine to operate with dual-fuel (diesel-biogas) system.
2- To study and analyze the system performance.

1.5 Project Lay-Out

Chapter one; summarized research problem and objectives, also it gives a brief introduction about renewable and conventional energy. Chapter two; this chapter illustrates biogas technology and the possibility of using biogas as a fuel for internal combustion engines (IC). Chapter three; consist system design, modification of the diesel engine and explain procedure of work. Chapter four; consist results and discussion. Chapter five; this chapter shows conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Society is today facing the problem of an increased demand for energy. The conventional energy sources are not able to meet this ever increasing demand. In recent years, environmental pollution and energy resource depletion have become serious issues for the world like global warming, acid rain, etc. In particular, research into automobile industry has attracted growing interest in an effort to improve engine efficiency and reduce harmful exhaust emissions. So, there is needed to be development of engines that can operate using more environmentally alternative fuel.

To save the conventional fuel by limiting its usage it is necessary to focus our attention towards renewable source of energy for power generation. Among the many different types of alternative fuels, biogas appears to be one of the most promising options. Producing renewable energy from our biodegradable wastes helps to tackle the energy crisis and biogas is particularly significant because of possibility of use in diesel engine, which used for powering of generators of electrical energy. This possibility of use is justified by biogas thermodynamics properties [1].

2.2 Diesel Generator-Set

A diesel generator-set is a combination of diesel engine and an alternator. Diesel engine is also used as power to drive generator to generate electricity. Diesel Engine is a compression ignition engine with diesel fuel. Usually, a diesel generator set is composed of three parts: diesel engine, AC synchronous generator and control panel.

2.2.1 Diesel engine

Diesel engines have high efficiency, durability, and reliability together with their low-operating cost. These important features make them the most preferred engines especially for heavy-duty vehicles. The interest in diesel engines has risen substantially day by day [2].

The working principle of diesel engine is that the air is compressed in the cylinder which causes the temperature to rise. The diesel oil sprayed into the cylinder self- burns, produce high temperature and high pressure gas. The fuel gas expansion forces the piston to work; the heat energy is converted into mechanical energy.

Working of Four Stroke Diesel Engine

The power generation process in four stroke diesel engine is also divided into four parts. Each part is known as piston stroke. In IC engine, stroke is referred to the maximum distance travel by the piston in a single direction. The piston is free to move only in upward and downward direction. In four strokes engine the piston move two times up and down and the crankshaft move two complete revolutions to complete four piston cycles. These are suction stroke, compression stroke, expansion stroke and exhaust stroke [3].

Suction stroke

In the suction stroke or intake stroke of diesel engine the piston start moves from top end of the cylinder to bottom end of the cylinder and simultaneously inlet valve opens. At this time air at atmospheric pressure drawn inside the cylinder through the inlet valve by a pump. The inlet valve remains open until the piston reaches the lower end of cylinder. After it inlet valve close and seal the upper end of the cylinder.

Figure 2.1: Suction stroke

Compression stroke

After the piston passes bottom end of the cylinder, it starts moving up. Both valves are closed and the cylinder is sealed at that time. The piston moves upward. This movement of piston compresses the air into a small space between the top of the piston and cylinder head. The air is compressed into 1/22 or less of its original volume. Due to this compression a high pressure and temperature generate inside the cylinder. Both the inlet and exhaust valves do not open during any part of this stroke. At the end of compression stroke the piston is at top end of the cylinder.

Figure 2.2: Compression stroke

Power stroke

At the end of the compression stroke when the piston is at top end of the cylinder a metered quantity of diesel is injected into the cylinder by the injector. The heat of compressed air ignites the diesel fuel and generates high pressure which pushes down the piston. The connection rod carries this force to the crankshaft which turns to move the vehicle. At the end of power stroke the piston reach the bottom end of cylinder.

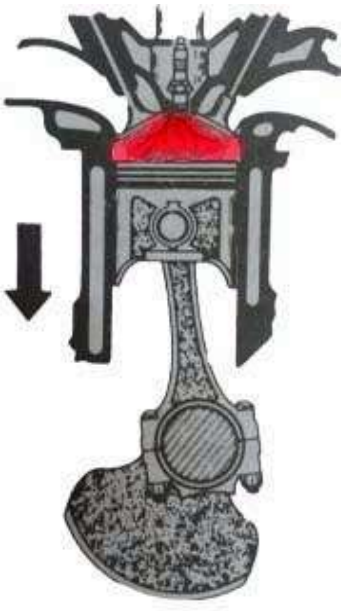

Figure 2.3: Power stroke

Exhaust stroke

When the piston reaches the bottom end of cylinder after the power stroke, the exhaust valve opens. At this time the burn gases inside the cylinder so the cylinder pressure is slightly high from atmospheric pressure. This pressure difference allows burn gases to escape through the exhaust port and the piston move through the top end of the cylinder. At the end of exhaust all burn gases escape and exhaust valve closed. Now again intake valve open and this process running until your vehicle starts.

Figure 2.4: Exhaust stroke

Diesel Engine-out Emissions

In addition to the widespread use of diesel engines with many advantages, they play an important role in environmental pollution problems worldwide. Diesel engines are considered as one of the largest contributors to environmental pollution caused by exhaust emissions, and they are responsible for several health problems as well. Many policies have been imposed worldwide in recent years to reduce negative effects of diesel engine emissions on human health and environment. The main pollutant emissions from diesel engines are (carbon monoxide-CO, hydrocarbons-HC and nitrogen oxides-NO_x) [2].

2.2.2 Synchronous generator

Synchronous machines are AC machines that have a field circuit supplied by an external DC source. Synchronous machines are having two major parts namely stationary part stator and a rotating field system called rotor. In a synchronous generator, a DC current is applied to the rotor winding producing a rotor magnetic field. The rotor is then driven by external means producing a rotating magnetic field, which induces a single-phase or a 3-phase voltage within the stator winding. Field windings are the windings producing the main magnetic field (rotor windings for synchronous machines); armature windings are the windings where the main voltage is induced (stator windings for synchronous machines) synchronous machines are classified as follow:

1. According to the prime mover:

a. Hydro generators: The generators which are driven by hydraulic turbines are called hydro generators. These are run at lower speeds less than 1000 rpm.
b. Turbo generators: These are the generators driven by steam turbines. These generators are run at very high speed of 1500rpm or above.
c. Engine driven Generators: These are driven by IC engines. These are run at a speed less than 1500 rpm. Hence the prime movers.

2. According to the rotor type:

a. Salient pole Machines: These types of machine have salient pole or projecting poles with concentrated field windings. This type of construction is for the machines which are driven by hydraulic turbines or Diesel engines.
b. Non-salient pole or cylindrical rotor or Round rotor Machines: These machines have a cylindrical smooth rotor construction with distributed field winding in slots. This type of rotor construction is employed for the machine driven by steam turbines.

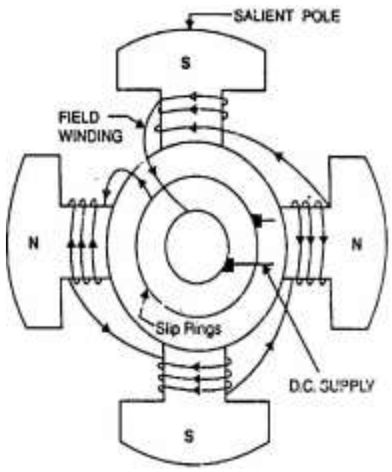

Figure 2.5: Salient pole Machine

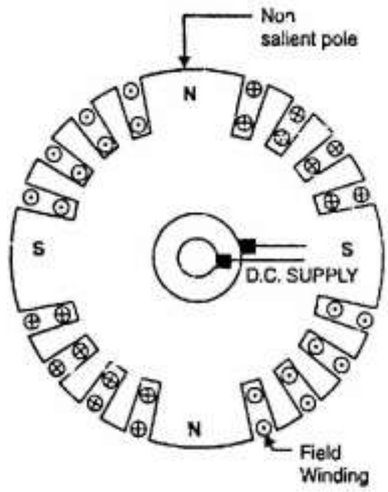

Figure 2.6: Non-salient pole Machine

3. According to the excitation system:

The basic function of an excitation system is to provide necessary direct current to the field winding of the synchronous generator. The excitation system must be able to automatically adjust the field current to maintain the required terminal voltage. The DC field current is obtained from a separate source called an exciter.

The following are the different types of excitation systems:

1. DC excitation systems

In DC excitation system, the field of the main synchronous generator is fed from a DC generator, called exciter. Since the field of the synchronous generator is in the rotor, the required field current is supplied to it through slip rings and brushes. The DC generator is driven from the same turbine shaft as the generator itself.

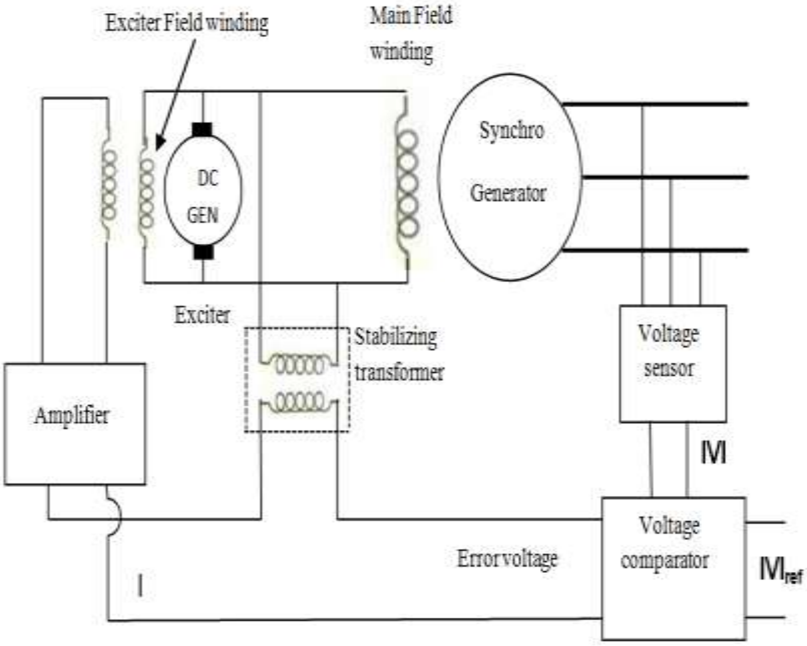

Figure 2.7: DC excitation systems

2. AC excitation systems

For medium size machines AC exciters are used in place of DC exciter. AC exciters are three phase AC generators. The output of an AC Exciter is rectified and supplied through the brushes, and the slip rings to the rotor winding of the synchronous machine.

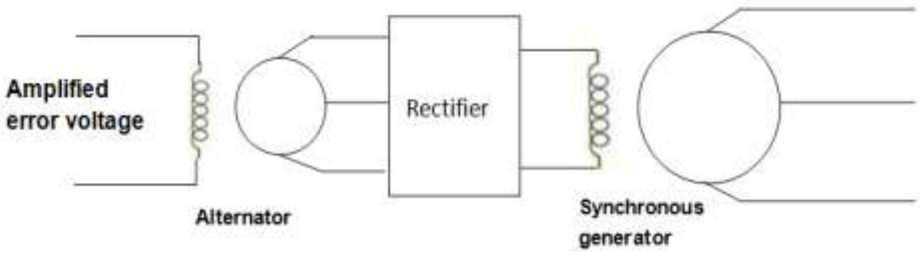

Figure 2.8: AC excitation system

3. Brushless AC excitation systems

For the large synchronous machines which are using brushless excitation system. A brushless exciter is a small direct coupled AC generator with its field circuit on the stator and the armature circuit on the rotor. The three phase output of the AC exciter generator is rectified by solid state rectifiers. The rectified output is connected directly to the field winding, thus eliminating the use of brushes and slip rings.

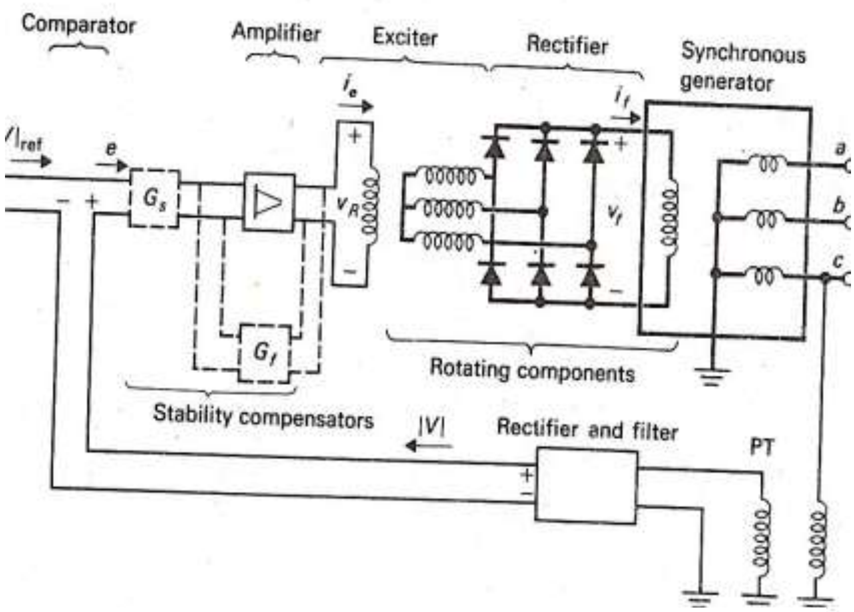

Figure 2.9: Brushless AC excitation

4. Static excitation systems

In static excitation system, a portion of the AC from each phase of synchronous generator output is fed back to the field windings, as DC excitations, through a system of transformers, rectifiers, and reactors. An external source of DC is necessary for initial excitation of the field windings. On engine driven generators, the initial excitation may be obtained from the storage batteries used to start the engine

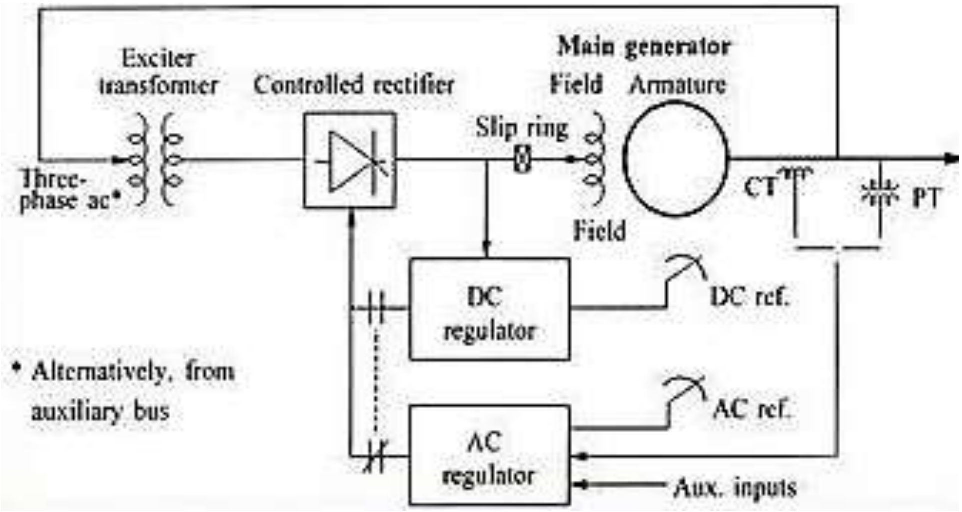

Figure 2.10: Static excitation system

5. Capacitor excitation system

The use of this technique is usually restricted to single phase generators with a rated output less than 10 kW. A separate excitation winding in the stator has a capacitor connected directly across its output as shown in Fig 2.11

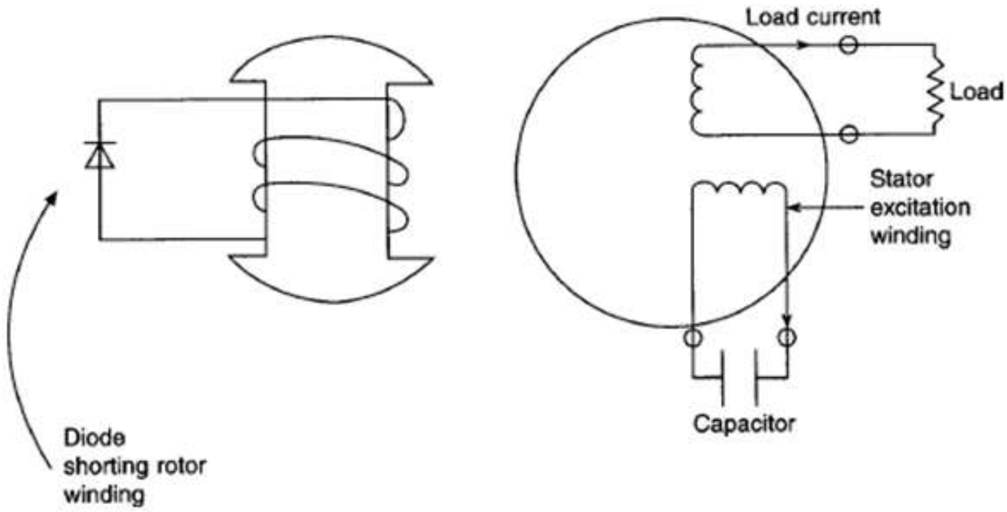

Figure 2.11: Capacitor excitation system

The rotor is usually of salient pole construction but in this case the rotor winding is shorted through a diode. On starting the residual flux in the rotor body induce a small voltage in the stator excitation winding and a current flow through the capacitor. This current produces two waves of magnetic flux around the air gap of the generator. One wave travels in the same direction as the rotor, to create armature reaction. The second wave travels in a direction opposite to the rotor, and induced a voltage in the rotor windings at twice the output frequency. The current circulated in the rotor windings by this induced voltage is rectified by the diode to produce a dc current. This dc current increases the magnetic flux in the machine, which in turn drives more rotor current through the stator excitation winding, which in turn produces more rotor current. This self-excitation process continues until flux reaches a point at which the magnetic circuit is saturated, and a stable voltage results.

2.2.3 Control panel

Visually a control panel is a set of displays that indicate the measurement of various parameters like voltage, current and frequency, through gauges and meters.

Figure 2.12: Control panel

2.3 Biogas

Biogas is a combustible mixture of gases. It consists mainly of methane (CH_4) and carbon dioxide (CO_2) and is formed from the anaerobic bacterial decomposition of organic compounds, i.e. without oxygen. The gases formed are the waste products of the respiration of these decomposer microorganisms and the composition of the gases depends on the substance that is being decomposed. If the material consists of mainly carbohydrates, such as glucose and other simple sugars and high-molecular compounds (polymers) such as cellulose and hemicellulose, the methane production is low. However, if the fat content is high, the methane production is likewise high. Methane – and whatever additional hydrogen there may be – makes up the combustible part of biogas. Methane is a colorless and odorless gas with a boiling point of -162°Cand it burns with a blue flame. Methane is also the main constituent (77-90%) of natural gas. Chemically, methane belongs to the alkanes and is the simplest possible form of these. At normal temperature and pressure, methane has a density of approximately 0.75 kg/m^3. Due to carbon dioxide being somewhat heavier, biogas has a slightly higher density of 1.15 kg/m^3.Pure methane has an upper calorific value of 39.8 MJ/m^3, which corresponds to 11.06 Kwh/m^3. If biogas is mixed with 10-20% air, you get explosive air, which – as the name indicates– is explosive [3].

2.3.1 Production of Biogas by Anaerobic Digestion

Anaerobic digestion is a natural process in which bacteria convert organic materials into biogas. The generation of biogas is the concept of anaerobic digestion, also called biological gasification. It is a naturally occurring, microbial process that converts organic matter to methane and carbon dioxide. The chemical reaction takes place in the presence of methanogen bacteria (microorganisms that produces methane in absence of oxygen) with water an essential medium. The anaerobic digestion process, as the name states, is one that functions without molecular oxygen. Ideally, in a biogas plant there should be no oxygen within the digester. Oxygen removal from the digester is important for two main reasons. First, the presence of oxygen leads to the creation of water, not methane. Second, oxygen is a contaminant in biogas and also a potential safety hazard. Due to presence of oxygen, calorific value of biogas becomes low [4].

$$\text{Organic Matter} \xrightarrow{\text{Microorganism}} CH_4 + CO_2 + H_2 + N_2 + H_2S \qquad (2.1)$$

Table 2.1: Biogas components

Components	Amount (%)
Methane (CH_4)	50 – 70
Carbon Dioxide (CO_2)	30 – 40
Hydrogen (H_2)	5 – 10
Nitrogen (N_2)	1 – 2
Water Vapor (H_2O)	0.3
Hydrogen Sulphide (H_2S)	Traces

2.3.2 Advantages of biogas technologies

The main advantages of biogas technologies are:

1. Renewable energy source.

The current global energy supply is highly dependent on fossil sources (crude oil, lignite, hard coal, natural gas). These are fossilized remains of dead plants and animals, which have been exposed to heat and pressure in the Earth's crust over hundreds of millions of years. For this reason, fossil fuels are non-renewable resources which reserves are being depleted much faster than new ones are being formed .The World's economies are dependent today of crude oil. There is some disagreement among scientists on how long this fossil resource will last but according to researchers, the peak oil production (The peak oil production is defined as the point in time at which the maximum rate of global production of crude oil is reached, after which the rate of production enters its terminal decline) has already occurred or it is expected to occur within the next period of time. Unlike fossil fuels, biogas from AD is permanently renewable, as it is produced on biomass, which is actually a living storage of solar energy through photosynthesis. Biogas from AD will not only improve the energy balance of a country but also make an important contribution to the preservation of the natural resources and to environmental protection.

2. Reduced greenhouse gas emissions and mitigation of global warming.

Utilization of fossil fuels such as lignite, hard coal, crude oil and natural gas converts carbon, stored for millions of years in the Earth's crust, and releases it as carbon dioxide (CO_2) into the atmosphere. An increase of the current CO_2 concentration in the atmosphere causes global warming as carbon dioxide is a greenhouse gas (GHG). The combustion of biogas also releases CO_2. However, the main difference, when compared to fossil fuels, is that the carbon in biogas was recently up taken from the atmosphere, by photosynthetic activity of the plants. The carbon cycle of biogas is thus closed within a very short time (between one and several years). Biogas production by AD reduces also emissions of methane (CH_4) and nitrous oxide (N_2O) from storage and utilization of untreated animal manure as fertilizer. The GHG potential of methane is higher than of carbon dioxide by 23 fold and of nitrous oxide by 296 fold. When biogas displaces fossil fuels from energy production and transport, a reduction of emissions of CO_2, CH_4 and N_2O will occur, contributing to mitigate global warming.

3. Reduced dependency on imported fossil fuels.

Fossil fuels are limited resources, concentrated in few geographical areas of our planet. This creates, for the countries outside this area, a permanent and insecure status of dependency on import of energy. Most European countries are strongly dependent on fossil energy imports from regions rich in fossil fuel sources such as Russia and the Middle East. Developing and implementing renewable energy systems such as biogas from AD, based on national and regional biomass resources, will increase security of national energy supply and diminish dependency on imported fuels.

4. Waste reduction.

One of the main advantages of biogas production is the ability to transform waste material into a valuable resource, by using it as substrate for AD. Many European countries are facing enormous problems associated with overproduction of organic wastes from industry, agriculture and households. Biogas production is an excellent way to comply with increasingly restrictive national and European regulations in this area and to utilize organic wastes for energy production, followed by recycling of the digested substrate as fertilizer. AD can also contribute to reducing the volume of waste and of costs for waste disposal.

5. Job creation.

Production of biogas from AD requires work power for production, collection and transport of AD feedstock, manufacture of technical equipment, construction, operation and maintenance of biogas plants. This means that the development of a national biogas sector contributes to the establishment of new enterprises, some with significant economic potential, increases the income in rural areas and creates new jobs.

6. Flexible and efficient end use of biogas

Biogas is a flexible energy carrier, suitable for many different applications. One of the simplest applications of biogas is the direct use for cooking and lighting, but in many countries biogas is used nowadays for combined heat and power generation (CHP) or it is upgraded and fed into natural gas grids, used as vehicle fuel or in fuel cells.

7. Low water inputs

Even when compared to other biofuels, biogas has some advantages. One of them is that the

AD process needs the lowest amount of process water. This is an important aspect related to the expected future water shortages in many regions of the world [5].

2.3.3 Utilizations of biogas

Biogas has many energy utilizations, depending on the nature of the biogas source and the local demand. Generally, biogas can be used for heat production by direct combustion, electricity production by fuel cells or micro-turbines, CHP generation or as vehicle fuel [6].

1. Heat.

The gas is combusted in a boiler. The heat generated warms up water which can be used to heat the digester and nearby buildings or be exchanged on a local district heating network. A gas boiler works like a boiler for solid and liquid fuels, but with the difference that the boiler is specially modified to combust gas.

2. Heat/Power.

Biogas can be used as a fuel in stationary engines, typically Otto or diesel engines or gas turbines. About 30-40% of the energy in the fuel is used to produce electricity while the remaining energy becomes heat.

3. Vehicle fuel.

Biogas can be used as a vehicle fuel for cars, buses and trucks, providing it is upgraded by removing carbon dioxide, water and hydrogen sulphide, water scrubbing, chemical scrubbing and PSA are the most widely used techniques for upgrading biogas to vehicle fuel quality. The gas must also be odorized and pressurized to around 200 bars before it can be used as vehicle fuel.

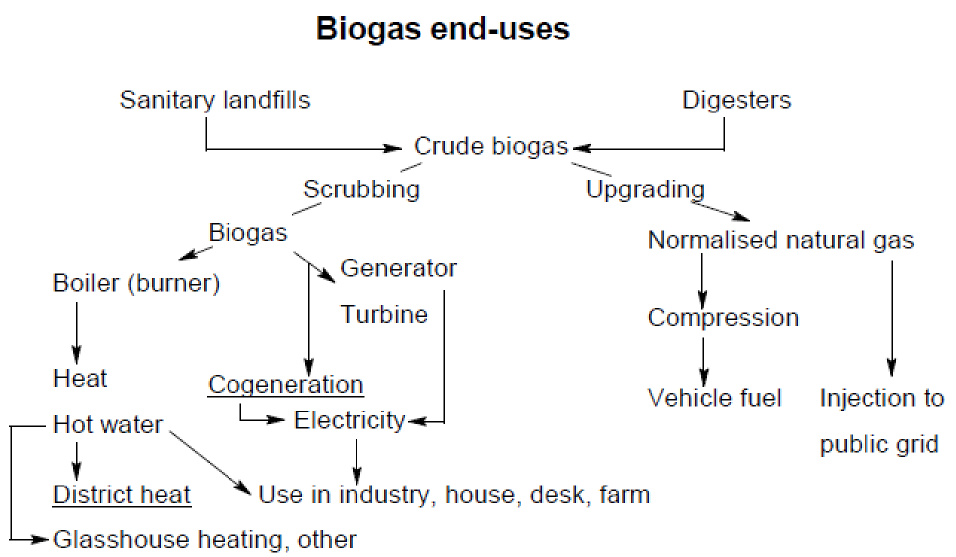

Figure 2.13: Biogas utilizations.

2.3.4 Biogas in IC Engine applications

Biogas can be used in both heavy duty and light duty vehicles. Light duty vehicles can normally run on biogas without any modifications whereas, heavy duty vehicles without closed loop control may have to be adjusted, if they run on biogas. Biogas provides a clean fuel for both SI (petrol) and CI (diesel) engines. Diesel engines require combination of biogas and diesel, while petrol engines run fully on biogas. Use of biogas as an engine fuel offers several advantages. Being a clean fuel biogas causes clean combustion and recesses contamination of engine oil. Biogas cannot be directly used in automobiles as it contains some other gases like CO_2, H_2S and water vapor. For use of biogas as a vehicle fuel, it is first upgraded by removing impurities like CO_2, H_2S and water vapor [7].

2.3.5 The principle and application of biogas-diesel dual-fuel engine

Biogas-diesel dual-fuel engine is on the basis of diesel engine, its working principle is to mix biogas and air in mixer to form combustible mixed gas. After the combustible mixed gas inhaled in the cylinder, and piston compressing and approaching to the top dead point, there is a little diesel spouted to the chamber; and then after the diesel burning, the mixed gas is immediately ignited to work. Under the normal situation, the quantity of leading diesel in dual-fuel engine is in 8% ~20%.

The work is basing on the biogas project scale of producing 1000 m^3 per day; the content of methane is 65%; the calorific value of biogas is 5500kCal/m^3. When unit is going to work, diesel can be used to start; when there is methane, diesel will reduce automatically until to the quantity of leading diesel. When biogas is insufficiency, diesel will increase willingly until to work with full diesel.

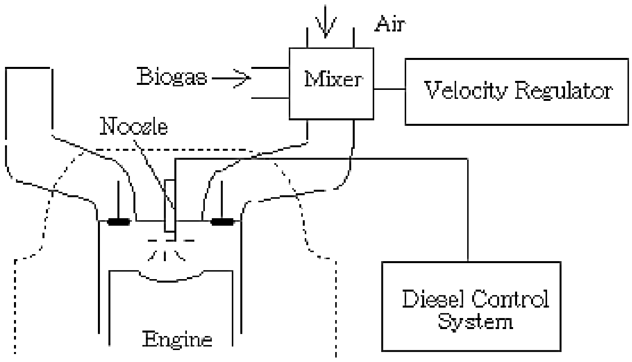

Figure 2.14: Schematic diagram of Biogas-diesel engine

The testing result indicates: the quantity of leading burning diesel ≤18%, the consumption of ratio is 0.41m^3/kWh; the temperature of exhaust is lower than original diesel engine about 20~30°C.[7] (showing in fig.3); having solved the engine problem of dependability, unit has been working normally until now from 1993. Using dual-fuel engine can also reduce exhaust smoke drastically (showing in fig.4); the measured smoke reduces 65% than before.

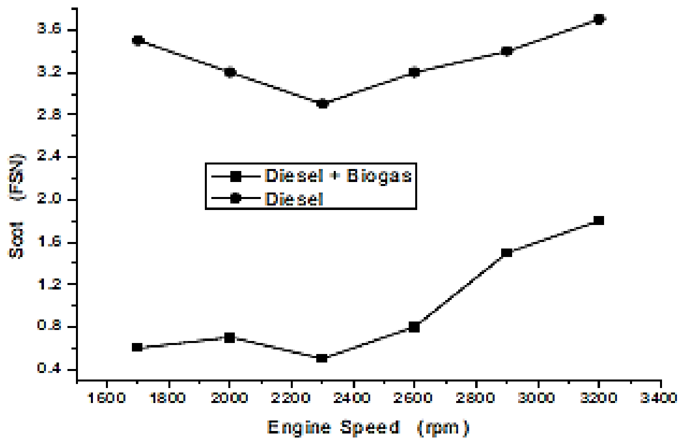

Figure 2.15: exhaust soot comparison

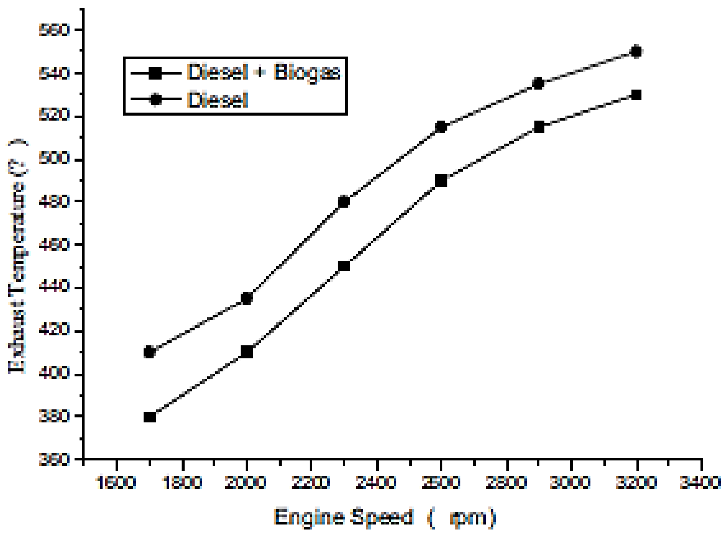

Figure 2.16: Exhaust temperature comparison

2.3.6 Problems of using Biogas in IC Engines

1. High CO_2 content reduces the power output, making it uneconomical as a transport fuel. It is possible to remove the CO_2 by washing the gas with water. The solution produced from washing out the CO_2 is acidic and needs careful disposal.

2. H_2S is acidic and if not removed can cause corrosion of engine parts within a matter of hours. It is easy to remove H_2S, by passing the gas through iron oxide (Fe_20_3 rusty nails are a good source) or zinc oxide (Z_nO). These materials can be re-generated on exposure to the air, although the smell of H_2S is unpleasant.

3. There is high residual moisture which can cause starting problems.

4. The gas can vary in quality and pressure.

2.3.7 Storage

There are two basic reasons for storing biogas, one is for later onsite usage and the other one is before and after transportation to offsite distribution points. Biogas can be stored at low, medium, and high pressures (Table2.2). The density of biogas is approximately 1.2 kg/m³, which is proximate to air at ambient condition. Hence, it requires a larger volume to store instead in compressed form. The critical pressure and temperature is of 75-98 bar and 82.5°C.This indicates that it can change its gaseous phase to liquid phase, when compressed up to the critical state [7].

Table 2.2: Most commonly used storage options.

Pressure	Storage device	Material
Low(13.8-41.4 KPa)	Water sealed gas holder	Steel
Low	Gas bag	Rubber, Plastic, Vinyl
Medium(105-197 KPa)	Propane or Butane tanks	Steel
High (20*10^6 KPa)	Commercial gas Cylinders	Alloy steel

2.3.8 Purification of Biogas for IC Engines

1. Removal of CO_2

CO_2 is high corrosive when wet and it has no combustion value so its removal is must to improve the biogas quality.

a) Caustic solution (NAOH)

$$40\%\ NAOH + CO_2 \longrightarrow NAHCO_3 \quad (2.2)$$

b) Refined process (K_2CO_3)

$$30\ \%\ K_2CO_3 + CO_2 \longrightarrow 2KCO_3 \quad (2.3)$$

CO_2 removal from biogas can be done by using chemical solvents like mono-ethanolamine (MEA), di-ethanolamine and tri- ethanolamine or aqueous solution of alkaline salts, i.e. sodium, calcium hydroxide and potassium. Biogas bubbled through 10% aqueous solution of MEA can reduce the CO_2 content from 40 to 0.5-1.0% by volume. Chemical agents like NaOH, $Ca(OH)_2$, and KOH can be used for CO_2 scrubbing from biogas. In alkaline solution the CO_2 absorption is assisted by agitation. NaOH solution having a rapid CO_2 absorption of 2.5-3.0% and the rate of absorption is affected by the concentration of solution [7].

2. Removal of H_2S

In physical separation pressurized water is used as absorbent, as both CO_2 and H_2S are water soluble agents. The water scrubbing method is used for biogas up gradation. The rate of CO_2 and H_2S absorption depends upon the factors such as, gas flow pressure, composition of +biogas, water flow rates, and purity of water and dimension of scrubbing tower [7].

CHAPTER THREE

BIOGAS-DIESEL DUAL FUAL SYSTEM DESIGN

3.1 Introduction

This chapter explains the method used in this project. It details the method adopted for design of the digester, modification the portable diesel-engine generator to operate with diesel-biogas dual fuel, and the system connections. All equipment and tools used during the project work are also shown in this chapter.

3.2 Components of Biogas-Diesel Dual Fuel System

The main components of biogas-diesel dual fuel system

3.2.1 Flex bag bio digester

A flexi bag bio digester was prepared, assembled and then installed at professor Saber laboratory north to the cars workshop at Sudan University Of science & Technology. The digester was exposed to a tensioning mechanism to increase the pressure inside the digester, also it was covered with protection bag to make protect from the outside conditions. The System has to main ports and both of them located at the bottom of the bio digester and connected with a tube an upper location to prevent from the leak and to ensure the flowing process [9].

Figure 3.1: Flex bag Bio digester

3.2.2 Biogas-diesel dual-fuel engine

The 5hp Yanmar diesel engine was modified to operate on the dual fuel system (biogas-diesel) as follow:

Figure 3.2: Diesel engine modification.

3.2.3 Synchronous Generator

Brushless synchronous generator, capacitor excitation system with the following specifications as shown in figure 3.3

Figure 3.3: brushless Synchronous generator nameplate.

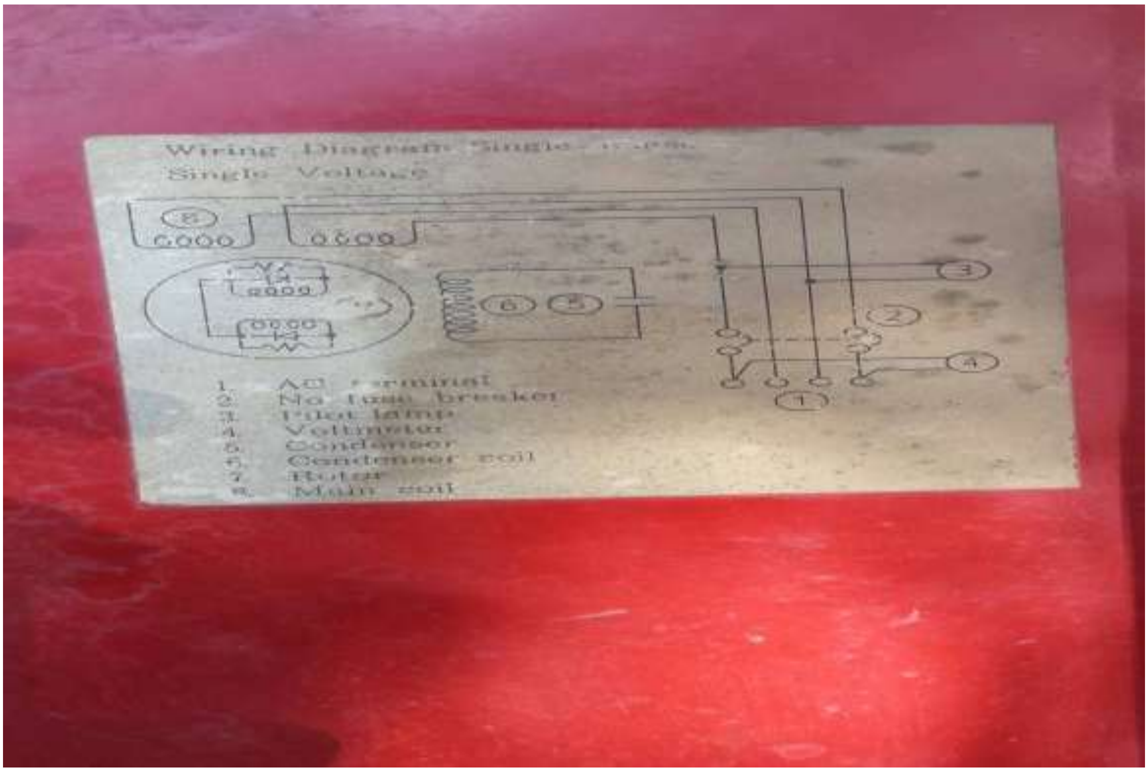

Figure 3.4: brushless synchronous generator wiring diagram

3.2.4Flowmeter

Flowmeter is a tool for measuring the biogas consumption.

Figure 3.5: Flow meter

3.2.5 H_2S scrubber

Is a tool to prevent engine corrosion.

Figure 3.6: Scrubber.

3.2.6 Gas analyzer

To measure the exhaust gases

Figure 3.7(a): Gas analyzer.

Figure 3.7(b): Gas analyzer printer.

3.3 The system connections

The components were connected as shown in figure 3.8

Figure 3.8: system connection.

3.4 Component and work tools used for biogas-diesel dual fuel system assembly

- Anaerobic digester (AD).
- scrubber.
- Barometer.
- Flow meter.
- Gen-set unit.
- Connecting wires.
- Ammeter.
- Hz meter.
- On-off switches.
- 10Amp Circuit Breaker.
- Load (boiler + lighting lamb).
- Decanter.

3.5 Experimental Procedure

The biogas-diesel dual fuel gen-set was assembled and prepared for experimentation at the Professor Sabir laboratory for biogas, School of Mechanical Engineering at SUST. After the digester unit was full with biogas with specifications in table 3-1, and the system connected as figure 3-7.

The following steps were followed experimentally

Step 1

Operate the gen-set by pure diesel fuel for 10 min with the full load with adjusted frequency of 50 Hz and full load terminal voltage, the consumption of pure diesel fuel for 10 min was registered, and the exhaust gases of full load pure diesel fuel was measured by using the gas analyzer, then the load was switched off by the circuit breaker while the gen-set was kept running ; to find out the gen-set regulations which determine the no load operating point (I .e no load frequency , no load terminal voltage), then the gen-set was switched off.

Step 2

Again the gen-set was operating for 10 min with no load, but with speed adjusted to give frequency of 40 Hz, then the consumption of pure diesel fuel for 10 min with adjusted frequency at 40 Hz was registered.

Step 3

The digester biogas with properties in the table 3-1 was inserted into the gen-set by progressively opening the biogas valve until the gen-set raised to no load operating point (I .e no load frequency, and no load terminal voltage).which are result from step 1, when the gen-set raised to no load operating point the operating time and the consumptions of diesel and biogas fuels was registered, and the exhaust gases was measured by using the gas analyzer.

Table 3.1: The biogas properties [9].

Property	Value	Unit
% CH_4	57	%volume
%CO_2	42.7	%volume
%traces	0.3	%volume
Pressure	4	Kpa
Calorific value	20.52	MJ / m^3

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Pure Diesel Fuel System

When gen-set was operated for 10 min , with pure diesel fuel to supply constant load ,and the frequency was adjusted to be 50 Hz, the terminal voltage was 170 volt, and the load current was 6.60 A , the exhaust gases was measured by using gas analyzer as shown in figure 4.2 , and the diesel consumption per second , as shown in the figure 4.1.

The rate of diesel consumption = $\frac{100}{10 \times 60}$= 0.166 ml / sec.

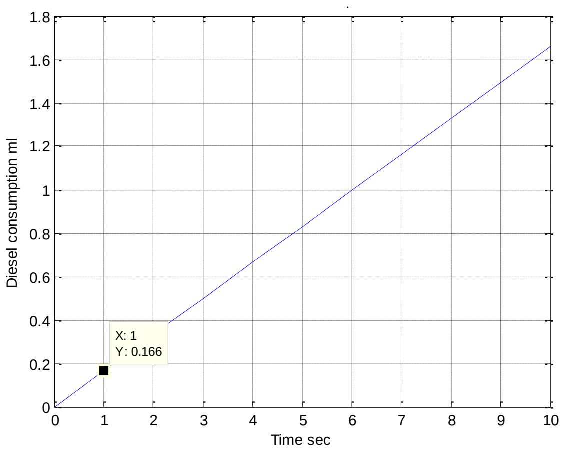

Figure 4.1: Diesel consumption in pure diesel fuel consumption curve.

Also the exhaust gases of pure diesel system was measured by gas analyzer which results as figure 4.2

Figure 4.2: Pure Diesel Fuel exhaust gases

After the load was switched off, the frequency rose to 51.5 Hz, and the terminal voltage rose to 180 volt, and then the gen-set was switched off. Thus, the gen-set regulation as shown in figure 4.3

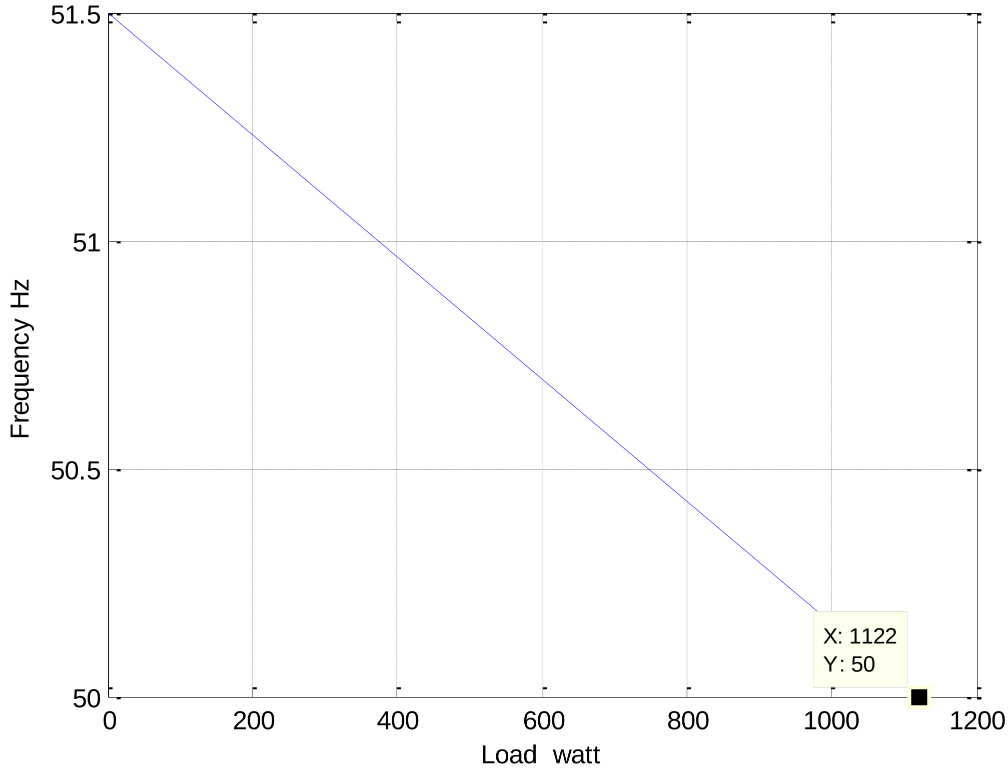

Figure 4.3: The gen-set regulation carve.

4.2 Biogas-Diesel Dual Fuel System

When The gen-set again switched on for 10 min at no load and the frequency was adjusted to 40 Hz, then the consumption of diesel fuel was measured as 55 ml, then when the biogas valve was opening progressively the gen-set frequency raised to 51.5 Hz for two seconds, then the biogas pressure dropped due to absence of biogas storage, and the gen-set frequency dropped again to 40 Hz and the consumption of the biogas was measured by using the biogas flow meter was 0.00028 m^3, also the exhaust gases of biogas-diesel dual fuel system was measured by using the gas analyzer as shown in figure 4.4

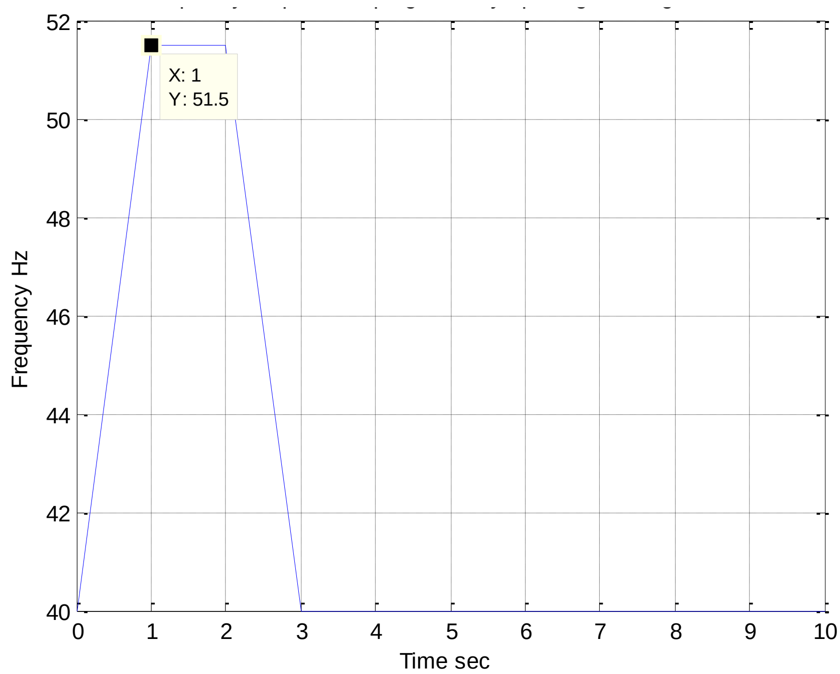

Figure 4.4: frequency response of progressively opening the Biogas valve.

The rate of diesel consumption = $\frac{55}{10\times60}$= 0.0916 ml /sec.

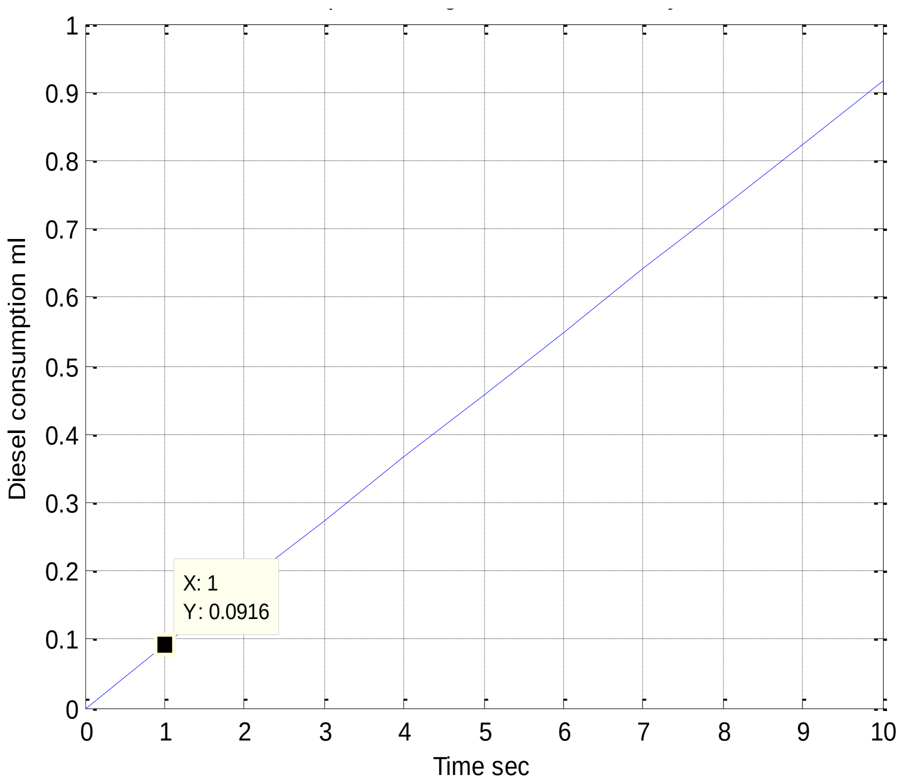

Figure 4.5: Diesel consumption in biogas-diesel dual fuel system curve.

The rate of biogas consumption =0.00028 ÷ 2 = 0.00014 m^3/sec

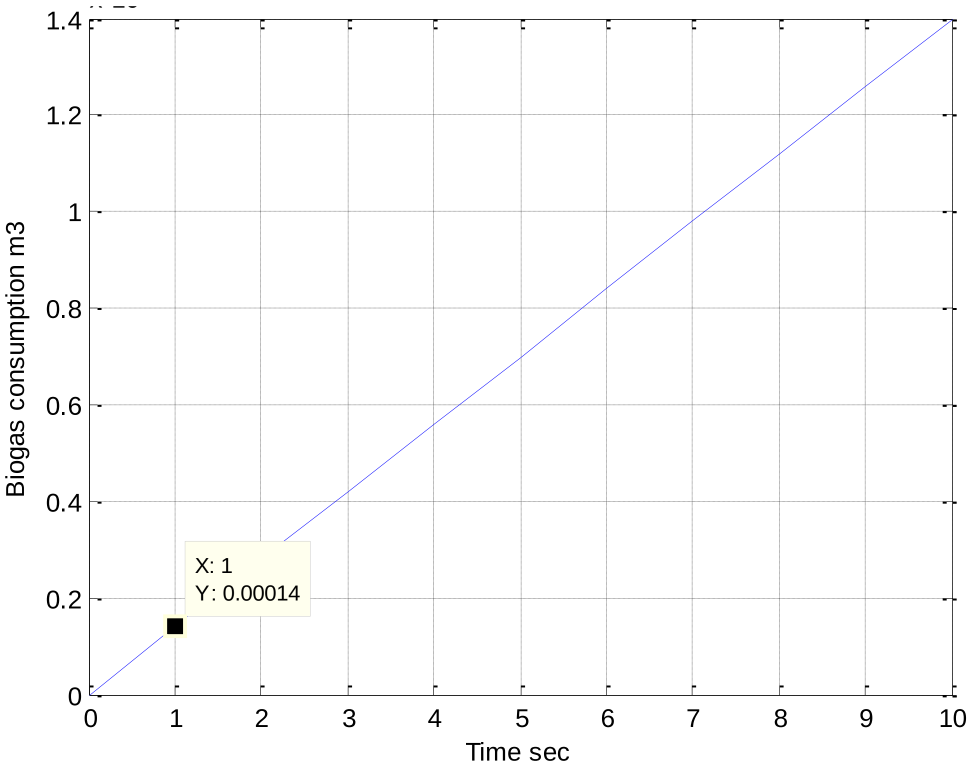

Figure 4.6: Biogas consumption in biogas-diesel dual fuel system curve.

The biogas consumption in m^3/kwh = $\frac{0.00014 \times 3600}{170 \times 6.6 \times 1 \times \times 10^{-3}} = 0.45\ m^3$/kwh.

The percentage saving in diesel fuel = $\frac{0.166-0.0916}{0.166} \times 100 = 45\%.$

Also the exhaust gases of biogas-diesel dual fuel system was measured by gas analyzer which results as figure 4.2

Figure 4.7: Biogas-diesel dual fuel system exhaust gases

4.3 comparisons between the exhaust gases in the pure diesel fuel system and biogas-diesel dual fuel system

The amount of CO and HC gases is increased in biogas-diesel dual fuel system as shown in table 4.1, due to reduced amount of air sucked in the combustion chamber of the engine, which is replaced by the biogas. Also the amount of CO_2 is increased; due to the amount of CO_2 consisted in the biogas.

The percentage increasing in $CO_2 = \frac{3.2-2.7}{2.7} \times 100$ =18.52%.

Table 4.1: comparison between the exhaust gases in pure diesel fuel system and biogas-diesel dual fuel system

Gas	Unit	Pure diesel fuel system	Biogas-diesel dual fuel system
CO	% volume	0.17	0.21
HC	ppm volume	0.0	221
CO_2	% volume	2.7	3.2
O_2	% volume	-	-

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The biogas had been produced from organic wastes by using the anaerobic digestion technology can be used as fuel for diesel-generator set; by modifying the diesel engine of generator to operate with biogas-diesel duel fuel system, although The amount of CO_2 exhaust had been increased in duel fuel system, due to the amount of CO_2 content in unburied biogas, the rate consumption of diesel fuel as reduce as the harmful emissions result from diesel combustion.

5.2 Recommendations

- Biogas purification.
- Storing biogas in tanks at high pressure.
- Using an external mixer.
- Employ an AVR system.

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APPENDIXES

MATLAB PROGRAM

FIGURE 1

```
clear
clc
t=0:1:10; % time in second.
x=0.166*t; % volume of diesel consumption ml
plot(t,x)
grid
xlabel('Time sec')
ylabel('Diesel consumption m3')
title('full Load Diesel Consumption')
```

FIGURE 2

```
clear
clc
load=[0 1122];      % load in watt.
frequency=[ 51.5 50];   % frequency in Hz.
plot(load,frequency)
grid
xlabel('Load watt');
ylabel('Frequency Hz');
title('The gen-set regulation curve');
```

FIGURE 3

```
clear
clc
frequency=[ 40 51.5 51.5 40 40 40 40 40 40 40 40  ];   % frequency in Hz.
time=[ 0 1 2 3 4 5 6 7 8 9 10];   % TIME in sec.
plot(time,frequency)
grid
xlabel('Time sec ');
ylabel('Frequency Hz');
title('Frequency response of progressively opening the biogas  valve');
```

FIGURE 4

```
clear
clc
t=0:1:10; % time second
x=0.0916*t; % volume of diesel consumption ml
plot(t,x)
grid
xlabel('Time sec')
ylabel('Diesel consumption ml')
title('Diesel Consumption in biogas-diesel dual fuel system curve')
```

FIGURE 5

```
clear
clc
t=0:1:10; % time in second
x=0.00014*t; % volume of biogas comsption m3
plot(t,x)
grid
xlabel('Time sec')
ylabel('Biogas consumption m3')
```