Conversion Of Diesel And Petrol Engines To Biogas Engines As An Energy Transition Strategy

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ABSTRACT

The use of internal combustion engines is a reliable and relatively efficient means of getting mechanical power for automotive propulsion and prime movers for generators in power plants. The transport sector is a major consumer of fossil fuels and accounts for over 60% of total air pollution coming from automobiles running on fossil fuels. In this study, an analysis was done on the feasibility of converting conventional engines to biogas or biomethane engines. The study showed that dual fuel engines can be used with little or no modifications to ran on biogas. However, to run on pure biogas as a fuel, the diesel engines need introduction of the ignition system in addition to gas storage and supply system. Conversion of a petrol engine to 100% biogas is the simplest as it requires minor adjustments related o introduction of the biogas storage and supply system.

Keywords
Biogas; biogas engine; engine performance; energy conservation; dual fuel engine, exhaust gas recirculation.

1. Introduction
The world is facing the challenge of growing energy demand with pressure on conventional energy sources which are mainly polluting fossil fuels and whose reserves are finite and diminishing (Singh and Layek 2019, These challenges and hence the need for sustainability in energy generation and use in an environmentally benign manner has created interest in biogas as an alternative fuel source for internal combustion engines (Kabeyi 2020, Kabeyi and Oludolapo 2020)..The concern over greenhouse gas emissions and global warming has led to demand for substitution of fossil fuels in powering internal combustion engines in transport and power generation (Ecotricity 2019). With world population explosion and increased energy demand and growing pollution from fossil fuels, there is need to substitute petrol and diesel in powering automobiles because their exhausts account for over 60% of total atmospheric pollution (Mitzlaff 1988) Biogas is particularly significant because of possibility of use in internal combustion engines, which are the main power source for transport vehicles and also commonly used for powering of generators in diesel power plants. This possibility of use is justified by biogas properties, which make it convenient for internal combustion engines (Awogbemi and Sunday 2015). A spark ignition engine running on a blend of biogas and petrol is more economical, less polluting and has lower fuel consumption.

Biogas is a mixture of gases produced by anaerobic digestion of biomass or biodegradable organic wastes in a controlled environment and process. The main constituents of biogas are methane and carbon dioxide, with methane being the main determinant of the energy potential of biogas (Adeyemo and Babatunde 2015), Diesel and petrol powered engines have their limitations such as high emissions, low efficiency and high costs (Senthilkumar K.and Vivekanandan, 2020), There are many advantages of biogas, but it is not so popular because of high NOx emission in some applications. In order to reduce NOx emission from the engine, it is necessary to keep max out combustion temperature under control. EGR technique is one of the methods to reduce NOx emission as it enables lesser flame temperature and oxygen concentration in combustion chamber. The main pollutants from biogas combustion are CO, HC, NOx, PM, and soot, etc. with NOx being the most injurious component of the exhaust emissions

The main challenge of converting a petrol/diesel engine is the reduction in rating of the engine, increased hydrocarbon emissions (Kabeyi. and Oludolapo 2020). Additionally biogas has a longer ignition delay which means that at the end of combustion stroke, burning is still going own which can cause high exhaust gas temperature, damage of exhaust valves, engine cooling and lubrication challenge and waste of fuel energy[9]. Methane also has slow burning velocity compared to gasoline and diesel fuel. (Senthilkumar K.and Vivekanandan, 2020,, Kabeyi. and Oludolapo 2020) Additionally use of biogas as engine fuel comes with its own challenges like need for engine modification of some parts and some engine specifications (Singla et al. 2019)

Biogas systems have significant environmental effects like reduced emission of methane from storage of liquid manure if the manure is used for biogas production. Bio-digestion leads to emissions of ammonia, methane, nitrous oxide and other elements which can be significant if the process is not well managed and controlled.(Kabeyi and Oludolap 2020, Mitzlaff 1988). However, bio digestion of bio wastes has indirect environmental benefits like reduction in emissions of greenhouse gases mainly in form of methane, nitrous oxide and pollutants which have a role in eutrophication (ammonia), and also leads to replacement of fossil fuels with biogas. Biogas production also helps in the disposal of solid wastes leading to significant size reduction and digestate for use as fertilizer Biogas can be used as a fuel for both compression ignition (diesel) and spark ignition engine (petrol). With its high octane number and high self-ignition temperature, biogas is ideal gas for use in spark ignition engines with little or no modifications (Singh, 2020) The overall objective of this study is to convert a petrol engine to a biogas engine as one of the pathways in the energy transitions. The study considers the technical, economic, and environmental implications of the conversion.

2. Biogas As An Engine Fuel Substitute For Diesel

Biogas –petrol blend as a fuel can be used in petrol engines in different proportions. For a 20% to 80% blend, a study by Adeyemo and Babatunde (2015) showed that the engine performance better with higher torque, indicated power, brake thermal efficiency and better fuel economy hence lower impact to the environment. In the study by Ambarita (2018) for a diesel engine of capacity 4.41 kW running on 60% biogas showed that the engine had higher thermal efficiency when run on pure biogas mode. In the dual fuel mode, diesel composition of 15 to 18% with the rest biogas gave best results.

2.1. Biogas as a fuel for internal combustion engines

Good quality biogas fuel should contain zero (0%) moisture (H_2O) content and hydrogen sulphite (H_2S). Biogas can substitute fossil fuels like natural gas, petrol and diesel for application in heating, transport and power generation (Ghenai and I. Janajreh 2015). The composition of biogas depends on the type of feedstock used and the production process (Ramesha 2015). The use of biogas in engines needs increased compression ratio in the spark ignition engine which leads to better engine power output but spark ignition engine operation with biogas containing significant fractions of inert gases such as CO_2 and N_2 exhibit or decrease engine performance compared with natural gas or gasoline and can also lead to more NOx emissions (Surataa 2014). Less modification is needed due to the high octane number and high self-ignition properties. The composition of biogas varies from feedstock to feedstock and the quality of the process control. However, biogas mainly consists of methane (CH_4) and carbon dioxide (CO_2 (Barragán-Escandón 2018)

Pure methane is an odorless gas made up of one atom of carbon and 4 atoms of hydrogen. Methane is lighter than air and is a highly flammable. It can form explosive mixtures with air at concentrations of 5 to 15%. Although methane is not toxic, it can cause death due to asphyxiation through oxygen displacement in confined environments. Methane is a powerful greenhouse gas having ability to remain in the atmosphere for up to 15 years, and is close to 20 more potent in trapping heat in the atmosphere than carbon dioxide for timescale of 20 years (AgSTAR 2020, Akpojaro 2019)This shows that uncontrolled biogas production and handling is very dangerous to the environment and effort should be made to have controlled bio-deration of organic wastes. Biogas can be used as a fuel or as a raw material for production of chemicals, hydrogen and/or synthesis gas etc. Other than methane and carbon dioxide as the main constituents of biogas, common contaminants present as trace elements include ammonia (NH_3), moisture, hydrogen sulfide (H_2S), nitrogen (N_2), methyl siloxanes, oxygen, halogenated volatile organic compounds (VOCs), hydrocarbons and carbon monoxide (CO). Some of the trace elements significantly affect biogas as a fuel and must be remove for quality purpose. They include hydrogen sulfide and carbon dioxide. As a fuel, biogas in form of biomethane, biogas upgrading has high operating costs and energy consumption which needs to be addressed Biogas is a mixture of several gases mainly 50-80% methane, 20-45% carbon dioxide, 2-8% water vapor, effluent and trace gases consisting mainly of O_2 N_2, NH_3 H_2 H_2S (Bhardwaj and Das 2017, Argo 2020) Table 1 shows the average composition of biogas.

Table 1. Average composition of biogas

	ELEMENT	COMPOSITION (%)
1	Methane	30-80%
2	Carbon dioxide	2-45%
3	Nitrogen	0-10%
4	Ammonia	0-0.05%
5	Moisture	2-8%
	Hydrogen	0-1%
6	Hydrogen sulphide	0-3%
7	Oxygen	0-3%
8	Ammonia	0-0.5%
9	R_2SiO	O-0.5 mg/m^3
10	C_xH_y	0-1%

From table 1, it is noted that methane and carbon dioxide is the main constituent of biogas, and its composition generally varies from 30 to 80% based on the quality of the feedstock and process control. The main determinant of the heating value of biogas is the composition of methane in biogas. The composition of methane in biogas varies from 45% to 75% by volume [26]. This variation implies that the ower heating value (LHV) of biogas is not constant but varies between 16 MJ/m^3) and 28 MJ/m^3. Biogas can be used directly to produce electricity and or can be combusted to release heat energy for cooking o perform some work as in internal combustion engines. The desirable characteristic of biogas as a fuel are. The following are general requirements of biogas engine fuel,

i.) Should have high methane content.
ii.) Water and CO_2 composition should be as low as possible for high caloric value.
iii.) The Sulphur content should be as low since it is converted to acids by condensation and combustion and cause corrosion.

The moisture content can be reduced by condensation in the gas storage or along the gas path while hydrogen sulphide (H_2S) content can be reduced by chemical, biological, or physical techniques (Energypedia 2020) The calorific value of biogas is 5000 to 7000 kcal/m^3 and is a function of methane concentration. Generally one cubic meter of biogas is an equivalent of 0.7 m^3 of natural gas, 0.7 kg of fuel oil, 0.6 kg of kerosene, 0.4 kg of petrol, 3.5 kg of wood, and 12 kg of manure briquettes, 4 kWh of electrical energy, 0.5 kg of carbon and 0.43 kg of butane , (Biogas 1988) At 0.1013 Mpa and 273K biogas has the following properties for 60% methane and 40% carbon dioxide composition.

Table 2. Biogas Properties (Energypedia 2020, A.A 2007, Biogas 1988)

	Property	Symbol	Value
1	Specific heat capacity	Cp	2.165 kJ/kgK
2	Molar mass	M	16.04
3	Gas constant	R	0.518 kJ/kg
4	Normal density	g	1.2 g/l
5	Critical density	g_c	320 g/l
6	Relative (to air) density	g_r	0.83
7	calorific value of biogas	LCV	22.6 Mj/m^3
8	Critical temperature	T	-2.5^{o}C
9	Critical pressure	p	7.3- 8.9 Mpa
10	Flammability limit content in air	v	6-12%
11	Ignition temperature	T	650-750^{o}C

From table 2, it is noted that biogas has molar mass of 16.04 and specific heat capacity of 2.165 kj/kgK and ignition temperature of 650 to 750^{o}C.
The thermodynamic properties of compressed natural gas, diesel and gasoline are presented in Table 2 below.

Table 3. Thermodynamic properties of compressed natural gas (Boretti 2020, Li 2004, Munde and Dalu 2012.)

	Property	**Unit**	**Gasoline**	**Diesel**	**Biomethane**
1	Stoichiometric Ratio	Ratio	14.2	15.0	15.7
2	Cetane number	Unit	N/A	40-55	N/A
3	Octane number	Unit	96	N/A	120-130
4	Lower calorific value	Mj/kg	42.2	43.5	45.9
5	Higher calorific value	Mj/kg	45	45.6	50.3
6	Density at 25ºC (DIN 51757)	Kg/m^3	749	837	2.52
7	Molecular weight	Kg/kmol	106.2	186	16
8	Minimum ignition energy	Mj	0.33	0.5	0.26
9	Lamilar flame speed	cm/sec	30	-	37.5
10	Flammability unit	Vol% in air	5.2	1	15.6
11	Adiabatic flame temp	K	2227	-	2266
12	Vaporization energy	Mj/m^2	293	192	215-276
13	Flash point	K	266	325	124
14	Combustion Energy	Kj/m^3	32.6	36.0	24.6
15	Auto ignition point	K	505-755	477-533	900

From table 3, it can be noted that CNG, diesel and gasoline have differences in thermodynamic properties with diesel being more dense and hence heavier with highest molecular weight, CHG has got higher autoignition point and is more flammable. With highest octane number, CNG is more ideal for spark ignition applications.

3. Construction of A Biogas Engine

The main components required in the conversion from petrol to biogas include are fuel storage cylinders, stainless steel fuel lines, gas supply regulator-reduces pressure and the fuel fuel-air mixer (special). For conversion from diesel to biogas they include, we modify the engine. This is done by injecting biogas into the engine on the air intake stroke (since methane does not ignite upon compression). The diesel is injected and ignited, which then ignites the biogas, effectively acting like a spark plug. The modifications needed include two fuel injection systems (for the biogas and the diesel), a second fuel line and a tank to hold the biogas.

3.2. Design and Dimensioning of Optimum Mixing Chamber

The mixing chamber is designed from mild steel pipes due to ease of fabrication and low cost of the material. The mixing chamber consists of a short flow pipe of circular cross-section, with an inlet for air and for biogas each and an outlet for the mixture. The air inlet to the chamber and the outlet for the air-fuel mixture is designed to be tangential to the main body so as to cause swirling of air during operation and facilitate better mixing of air and fuel gas. The gas inlet is made from a copper tube closed at one end and with three holes drilled on its side. The gas tube is axially connected to the chamber so that biogas exited radially as it mixes with the swirling air. This design creates turbulence in the flow of air and fuel within the chamber resulting in homogeneous mixing of biogas and air before charging into the engine. Design of the mixing chamber is based on engine capacity i.e., cubic volume of engine, volume of the air filter, diameter of the air intake manifold, rated power of engine, biogas density, calorific value, and biogas supply pressure.

Length of the mixing chamber

A nominal diameter of 100 mm and thickness 3 mm was selected this is from the recommended diameter of half the chamber body diameter; this creates the required swirling motion of air and air-fuel mixture inside the mixing chamber. This diameter also matches the air filter connection (50 mm) and the engine intake manifold diameter (50 mm) and therefore facilitates smooth flow of air and air-fuel mixture respectively, as recommended and therefore the formula for volume of a cylinder is used in finding the length. The volume (1528 cm^3) of the mixing chamber was guided by the cubic capacity of the engine and volume of the air filter. The larger volume between the two was taken as the volume of the chamber; this is the recommended design procedure so as to ensure sufficient air is delivered to the engine.

$$V = \frac{\pi}{4} d^2 l \qquad \text{Equation 3.1}$$

Where V = 1528 cm^3 = volume of the chamber,
d = 100 mm = diameter of the chamber,
l=length of the chamber.
The design length of the chamber was found to be 200 mm.
If it is necessary to install the mixing chamber separately from the engine due to scarcity of space or the existence of more than one engine inlet refer to explanations given above for tube-type mixers.

3.3. Sizing of the Gas Pipe

The gas pipe dimension is mainly dependent on fuel energy required by the engine at maximum rated power and speed i.e., 7.5 kW and 1500 rpm respectively and the volumetric calorific value of biogas i.e., 23,302 kJ/m^3. The procedure involved first evaluating the volumetric air intake, V_{air} (4-stroke engine)

$$V_{air} = \frac{V_h n}{2 \times 60 \times 1000} \eta_{vol}$$

Where V_{air} = volumetric air intake in m^3/s, η_{vol} = volumetric efficiency, V_h = engine cubic capacity in m^3 and n = engine speed in rpm.
The intake velocity, c_i was then evaluated from

$$c_i = \frac{4V}{\pi d^2}$$

Where c_i = intake velocity in m/s, V = volumetric air intake in m^3/s, d = manifold connection diameter or air inlet diameter = 50 mm.
Volume flow of biogas (fuel consumption, f_c) at rated power was evaluated using

$$f_c = \frac{sfcP}{3600}$$

Where f_c = biogas fuel consumption in m^3/s, sfc = 0.8 m^3/kWh = engine specific fuel (gas) consumption and P = 7.5 kW = rated power of engine.
Assuming that maximum substitution of diesel with biogas would be 80% i.e percentage of biogas in total fuel (for dual fuel operation), based on literature, Eq. (3.5) was used to calculate the fuel consumption.

$f_{cd} = 0.8 f_c$,

Where f_{cd} = biogas fuel consumption in dual fuel operation (m^3/s).
The cross-sectional area, A_g and diameter, d_g of nozzle was then calculated from

$$A_g = \frac{f_{c_d}}{c_g}$$

Where A_g = cross-sectional area of nozzle, f_{cd} = biogas fuel consumption in dual fuel operation (m^3/s), c_g = velocity at gas nozzle in m/s.

$$d_g = \sqrt{\frac{4 \cdot A_g}{\pi}}$$

Where d_g = diameter of nozzle in m and A_g = cross-sectional area of nozzle in m^2.

The design procedure gave a nozzle diameter of d_g = 9 mm, for operation under the conditions specified. However, a 10% safety factor was included as an allowance; should the engine be operated at a higher rate of power and speed.n

The air inlet to the chamber and the outlet for the air-fuel mixture were designed to be tangential to the main body so as to cause swirling of air during operation and facilitate better mixing of air and fuel gas.The minimum distance between the gas inlet and the inlet to the engine manifold one should consider twice the tube (inlet) diameter. The gas tube should be axially connected to the chamber so that biogas exits radially as it mixes with the swirling air. This design will create turbulence in the flow of air and fuel within the chamber resulting in homogeneous mixing of biogas and air before charging into the engine.

3.4. Control Mechanism

Almost every diesel engine is equipped with a speed governor. Governors may be different in their design and function. The main difference is determined by the original use of the engine, whether for a vehicle or for stationary purpose. The governor/injector system should be retained in order to facilitate operation on diesel fuel alone whenever required.

The governor will act to vary the amount of fuel injected in order to maintain the required speed at any load. However, the speed will be constant within certain limits only, usually + 2- 5%. The control characteristics of the governor are usually very "steep", i.e., within a certain small variation of speed the control rack hence amount of fuel are varied from 100% to minimum (idling).

3.4.1 Automatic Control

The gas flow needs to be controlled by a butterfly valve which is operated between fully open and fully closed position by short movements, i.e., a 90° or smaller angular movement, and with little force. The butterfly valve can be operated by a solenoid mechanism (positioner/actuator) which receives its impulse from an electronic control unit which again has a sensor for the engine or generator speed or frequency. The minimum diesel fuel for ignition is set at a fixed point in the injector pump whereby the control rack is blocked in the respective position, i.e., the fuel injected does not change with speed alterations. The idling adjustment screw on the governor can be used for setting the constant minimum pilot fuel injection (Table 4).

Table 4. Materials and Equipment for an optimum mixing chamber

Part	Material /Type	Reason for choice
Mixing chamber	Mild steel pipes	Ease of fabrication and low cost of the material
Gas inlet	Galvanized steel or copper	High thermal conductivity, resistant to corrosion and relatively non-reactive.
Bosch Electronic control unit	MD1CP	-Common platform for gasoline, diesel, and alternative powertrains with increased performance and scalability for current and future customer requirements -Long-term availability of microcontrollers and reusability of application software - Supports functional safety requirements (ISO 26262) and offers new kinds of access and tuning protection

Design of the mixing chamber is based on engine capacity i.e. cubic volume of engine, volume of the air filter, diameter of the air intake manifold, rated power of engine, biogas density, calorific value and biogas supply pressure. The parameters that guided the design of the mixing chamber are summarized in the table 3.

3.5. Diesel Fuel Consumption

The rate of diesel fuel consumption in each test was measured by noting the time taken to consume 20 ml of the fuel then dividing the mass by the time. The mass flow rate was then obtained by multiplying the volume flow rate by the density of the fuel. The fuel tank was filled before the start of every experiment, while keeping the tank outlet valve closed. At the start of the experiment, the fuel tank outlet valve was opened to allow fuel into the burette and to fill the fuel line. The fuel tank outlet valve was closed, and the engine allowed to run on fuel from the metering burette while noting the time taken to consume 20 ml of fuel. The procedure was repeated to obtain five sets of data for every loading condition, from no load to full load. The recorded data for volume of fuel consumed and the time taken was used to calculate the fuel flow rate into the engine, using:

$$\dot{m}_f = \frac{V\rho}{t}$$

Where $\dot{m}_f$= rate of fuel flow into the engine in kg/s, V = volume of fuel consumed in m^3, ρ = density of diesel in kg/m^3 and t = time taken to consume the measured volume of the fuel in seconds.

The percent diesel substitution in dual fuel operation was calculated by subtracting diesel consumption by the engine on dual fuel mode from diesel consumption by the engine on single fuel mode (diesel alone) and then dividing the difference by diesel consumption by the engine on single fuel mode

$$ds = \frac{100(D_d - D_{dg})}{D_d}$$

Where ds = diesel substitution, per cent, D_d = diesel consumption by the engine on single fuel mode, in kg/h, D_{dg} = diesel consumption by the engine on dual fuel mode, in kg/h.

3.6. Biogas Fuel Consumption

During dual fuel operation, the procedure for metering the amount of diesel consumed was maintained as described in the previous section while the quantity of biogas consumed was measured using a flow meter. The mass flow rate was then computed from the known density of the fuel (1.22 kg/m^3). The flow meter had an accuracy of 0.001 m^3 and a range of 0 to 10000 m^3. For every test, the initial and final meter reading was recorded as well as time taken to consume the gas. The volume of gas consumed by the engine was calculated by subtracting the initial from the final gas reading. Mass flow rate was calculated using volume of gas consumed, density of the gas and the time taken.

3.6 Engine Brake Power

Engine brake power is the power output of the drive shaft of an engine i.e the power actually delivered by the engine. For each load value, five sets of data were taken, averaged and the brake horsepower obtained from the calculation formula given by

$$P.S = \frac{WN}{1000}$$

Where $P.S$ = brake horsepower, W = torque indication in kg, N = revolution per minute.

3.7 Brake Specific Fuel Consumption

Specific fuel consumption is the ratio of rate of fuel flow into the engine to the engine power.

$$sfc = \frac{\dot{m}_f}{\dot{W}}$$

Where sfc = specific fuel consumption, $\dot{m}_f$= rate of fuel flow into engine and $\dot{W}$ = engine power.
Brake power gives the brake specific fuel consumption.

$$bsfc = \frac{\dot{m}_f}{\dot{W}_b}$$

Where bsfc = brake specific fuel consumption, $\dot{m}_f$= rate of fuel flow into the engine and $\dot{W}_b$ = brake engine power. The mass of gas consumed was determined by multiplication of the volumetric gas consumption by its density. In the setup, the volumetric gas consumption for biogas was measured by using a gas flow meter and then calculated for mass of gas consumption using density of biogas (1.22 kg/m^3). The time taken by the engine to consume a fixed volume was measured using a stopwatch.

3.8 Brake Thermal Efficiency

Thermal efficiency is the ratio of engine output power to the power supplied by the fuel.

$$\eta_{th} = \frac{\dot{W}}{\dot{m}_f CV}$$

Where η_{th} = thermal efficiency, $\dot{W}$ = engine power, $\dot{m}_f$ = rate of fuel flow into engine and CV = calorific value of fuel.

Brake power gives the brake thermal efficiency.

$$\eta_{bth} = \frac{\dot{W}_b}{\dot{m}_f CV}$$

Where η_{bth} = brake thermal efficiency, $\dot{W}_b$ = brake power, $\dot{m}_f$ = rate of fuel flow into engine and CV = calorific value of fuel.

3.9 Brake thermal efficiency of engine on dual fuel mode

The formula used for calculating the brake thermal efficiency of engine on dual fuel mode is given by:

$$\eta_{bth} = \frac{\dot{W}_b}{\dot{m}_{fd} CV_d + \dot{m}_{fg} CV_g}$$

Where η_{bth} = brake thermal efficiency, $\dot{W}_b$ = brake power, $\dot{m}_{fd}$ = rate of flow of diesel fuel into engine, $\dot{m}_{fg}$ = rate of flow of biogas fuel into engine, CV_d = calorific value of diesel fuel and CV_g = calorific value of biogas fuel, $\dot{m}_{fd}CV_d$ = power input from diesel (pilot fuel) and $\dot{m}_{fg}CV_g$ = power input from biogas.

4. Conversion to Biogas/Biomethane

4.1. Converting Diesel engines to gas engines

It is possible to convert a diesel engine to a full gas engine but for this to work, several modifications should be done [(Mitzlaff 2021). They include the following changes are necessary:

i.) Remove the engine fuel injector pump and fuel injection nozzles.

ii.) Reduce the design compression ratio to prevent fuel pre-ignition by increasing the stroke volume.

a. Exchange the piston for one that effects a lower compression ratio,
b. Cut off o material from the piston top and modify the piston groove.
c. Machine off some material from the combustion chamber side on the cylinder head,
d. The piston is modified by use of thicker cylinder gasket (Mitzlaff 2021).

iii.) Modification also involves the introduction of an ignition system with distributor, ignition coil, and spark plugs for ignition. The ignition system chosen is a function of the number of cylinders for the engine. For single cylinder engine, a transistor type system may be required and often a magnet is installed on the flywheel. But the multi-cylinder engines require installation an ignition distributor (Mitzlaff 2021)

iv.) Installation of electric supply (alternator),

Modification also requires the introduction of an ignition system for conversion to a spark ignition system with an alternator and storages device in form of batteries with a charge regulator. Some diesel engines already have alternators and batteries for the stator which can serve the purpose.

v.) installation of a mixing device

This is needed to mix the air and fuel for supply to the combustion chamber. This may consist of a venturi mixer, a simple mixing tank or pneumatic control valve (Mitzlaff 2021)

vi.) The engine speed control is achieved by variation of the supply of the air/fuel mixture.

4.2. Conversion of Diesel Engine to Dual-Fuel Engine

By 31 July 2019, the world had 27,765,376 natural gas vehicles using engines running on natural gas as compression ignition or spark ignition engine modes. The compression ignition natural gas engines are more popular because of their higher reliability and fuel efficiency.. In the conversion of a diesel engine to dual engine, the main engine components and systems that should be modified include the fuel system, its fuel injection system, the fuel gas system, air intake or charging system, the engine exhaust System, the combustion chamber, and Control System.

Overall, the air fuel ration has to be reduced (Li 2004). On engine performance, the efficiency varies with the power required for gas compression, hence the more the power requirement, the less the engine efficiency. For a gas engine optimum shaft thermal efficiency of 49.6% in gas operation at about 85% to 90% loading can be realized upon conversion. The compression energy is about 2.5% of shaft power shaft power output, at inlet pressure of 16 bar. If the gas is delivered as a liquid, the compression work consumes about 0.8% of engine shaft power output.

In a study at the gas powered Ringgold Cogen power station, the plant heat rate is about 9300 kJ/kWh which corresponds to an efficiency of around 39% with plant availability of about 90.1% over five years (12 months) of operation (Li 2004) In this plant, the diesel engines ran on natural gas compressed to 250 bars. The injection was with pilot oil amount of about 5% of total fuel intake. The Ringgold Cogen Power plant's average specific lubricating oil consumption was about 0.8 g/kWh [35].The main limitation with gas engines is higher NOx emissions compared to 100% diesel engine fuel mode. As a control measure, a catalytic exhaust purification system may be is recommended to reduce NOx emissions from a realized level of 1300 mg/MJ(fuel) to a desirable level of 200 mg/MJ or less as in a case of existing natural gas powerplant plant in Finland (Singh 2019)

i.) Introduction of Dual-Fuel Electronic Control Unit (ECU).

The role of the ECU is to send high speed pulse-modulated signals to natural gas and diesel fuel injectors and hence control amount of fuel injected. This control unit determines and controls the supply of dual fuel to the engine ensuring optimum fuel control which is usually 8% diesel combined with 92% natural gas under steady conditions.

ii.) Turbo-Charger Air Bypass (TAB).

This controls the amount of air provided by the turbocharger by use of bypass valve usually of a butterfly design.

iii.) Pistons and combustion chamber modification

The overall objective is to change the compression ratio and are redesigned the combustion chamber to influence combustion characteristics including flame flow. The piston groove may be modified as well as the bowl while the length of the connecting rod may also need modification.

The conversion to CNG for CIE (compression ignition engines) leads to better engine performance with reduction in engine emissions which are mainly in the form of nitrogen oxides (NOx), (HC) hydrocarbons, and carbon dioxide (CO_2). However, other studies have shown that the use of CNG diesel engines ultimately leads to an increase in NOx emissions in the engine exhaust. In another study, a performance analysis was done for a diesel-CNG (dual fuel) engine of specifications 2.5-liter (cc) cylinder with 4-cylinders and a common rail direct injection diesel engine. The engine performance and exhaust gas emissions of several diesel-CNG dual fuel blend ratios, i.e., 100:0, 90:10, 80:20, 70:30, 60:40 and 50:50 was analysed. In this study, it was observed that for engine loading of 100%, 75%, 50%, the engine brake torque and brake power at engine at a speed between 2000 and 3000 rpm was higher compared with 100% diesel only engine mode. However, it was at 50:50 diesel-CNG ration that the highest brake torque and brake power were achieved but with the highest brake specific fuel consumption, meaning that more fuel was consumed. Emissions for the dual fuel mode in this study showed that as more and more CNG was added to the dual fuel mode, there was an increase in the unburned hydrocarbons and carbon dioxide emission, but CO emission decreased. The study further showed that NOx emission concentration is generally remains unaffected by the changes in the natural gas-diesel fuel ratio in the engine. Therefore, this implies that the conversion

5. Results and Dicussion

Biogas in form of biomethane is the cleaner fuel compared to coal and oil. Coal and oil consist of complex molecules with higher carbon ratios and higher composition of pollutant forming sulphur and nitrogen compared with natural gas. These leads to higher emissions of sulphur dioxide and nitrogen oxides (NOx) in addition to ash. On the other hand, natural gas produces minimal amounts of sulphur dioxide, nitrogen oxides and almost no ash or particulate matter and emits lower levels of carbon dioxide (CO_2), carbon monoxide (CO) and other reactive hydrocarbons. This makes natural gas an environmentally superior fossil fuel compared to coal and oi, Table 5 below shows the emission levels from natural gas, oil, and coal.

Table 5. Fossil fuel emissions (pounds/per Billion Btu of energy output

	Pollutant	Natural gas	Oil	Coal	Remarks

1	Carbon dioxide	117,000	164,000	208,000	Natural gas has least CO_2 emissions
2	Carbon monoxide	40	33	208	Oil produces least CO emissions
3	Nitrogen oxides	92	448	457	Natural gas emits the least amounts of nitrogen oxides
4	Sulfur dioxide	1	1,122	2,591	Natural gas emits insignificant amount of sulfur dioxide
5	Particulates	7	84	2,744	Natural gas emits negligible amounts of particulates
6	Mercury	0.000	0.007	0.016	Natural gas does not emit mercury to the environment
7	Total emissions	117,140	165,687	214,000	

From table 3 above, it is noted that between natural gas, oil and coal, natural gas produces the least total emissions followed by oil and coal respectively. It produces 82.7% less total emissions than coal and 44.4 less total emission than oil. Since natural gas is the cleanest fossil fuel, it can be used in many applications to reduce the negative environmental impact of fossil fuel combustion. The use of natural gas in power generation reduces cases of fog since it leads to less NOx emissions which is the main cause of smog. Acid rain whose principal sources SO_2 and NOx is also reduced by use of natural gas in place of oil and coal since natural gas emits almost no SO_2 and emits up to 80% less NO_x than coal (Munde et l., 2012). A shift from coal and oil to natural gas will significantly reduce pollution from power plants since power generation is a leader in greenhouse gas emissions, example in 2002, power generation accounted for 67% of Sulphur dioxide emissions, 40% of CO_2 emissions, 25% of NOx emissions, and 34% of mercury emissions in the US because coal fired powerplants have a significant contribution to generation capacity. It can also be noted that natural gas combined cycle powerplant emit about 50% as much CO_2 as modern super critical coal power plant.

6. Conclusion

The results of this study showed that biogas is a feasible substitute of fossil fuel as an alternative fuel, but conversion should be carefully done to minimize engine emission like NOx, CO, particulate matter, and others. The use of a heat exchanger in the EGR system resulted in reduction of emissions in the atmosphere. The use of the EGR in improved thermal efficiency and is eco-friendly but optimum level of recirculation should be established for tradeoff between NO_X and other emissions which are influenced differently. The modification of diesel engine into a dual fuel engine would involve introducing an air-fuel mixing chamber along the air intake system to provide an effective means of admitting the gaseous fuel into the combustion chamber and for homogenous mixing of air and the gaseous fuel. A modification has also to be made at the diesel injection pump to allow adjustment of the injection quantities of the pilot fuel as may be necessary. The study showed that brake power and the brake thermal efficiency decreased with use of biogas due to the calorific value of biogas being lower compared to diesel. The lower heating value of biogas is at least 50% lower than for diesel. Both CO and HC emissions of the dual fuel engine are higher than for diesel operation by upto 2 and 12 times respectively. This was majorly attributed to displacement of the air necessary for combustion with biogas. Biogas is a good fuel for dual fuel engines and can form a perfect supplement to the fossil fuels used in the country since it is renewable and affordable. Biogas can also be used alone but adjustment to the engine may be necessary depending on whether the engine is compression ignition or spark ignition.

This study demostrated that a petrol and biogas-petrol blend yield higher torque, more brake power, higher indicated power, high brake thermal efficiency, and higher brake mean effective pressure. But, it has lower fuel consumption and creates higher exhaust temperature than petrol. The stufy showed that a spark ignition engine fueld by biogas-petrol was more economical, ha has low fuel consumption and contributes to to fertilizer production and better sanitation. Therfore biogas has a significant role to place in the energy transition by cutting down emissions in bothe power generation and transport indiustry.

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