A Study on Application of Biogas as fuel in Compression Ignition Engines

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Abstract-Biogas derived from organic wastes is considered as good alternative to petroleum fuels. It can be used in compression ignition (CI) engines, because of its better mixing ability with air and clean burning nature. Biogas is produced by anaerobic digestion of various organic substances such as kitchen wastes, agricultural wastes, municipal solid wastes, cow dung etc., in absence of oxygen, which offers low cost and low emissions than any other secondary fuels. It can be a supplemented to liquefied petroleum gas (LPG) and compressed natural gas (CNG), if it is used in compressed form in cylinders. This study reviews the current status and perspectives of biogas production, its' up gradation through purification & storage methods and its engine applications. Here through detailed literature review, the combustion characteristics of biogas in compression ignition engines are investigated.

Key words- Anaerobic digestion, Biogas, Dual fuel, HCCI, I.C engine, C.I engine.

I. INTRODUCTION

The increasing energy demand and depletion of fossil fuel resources inevitably necessitate for the optimum utilization of exhaustible fossil fuel and non-renewable energy resources. Hence, the scientists are looking for alternative fuels and biogas is one of the available sources to fulfill the energy demand. 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 internal combustion (IC) engines, which are the main power source for transport vehicles and also commonly used for powering of generators of electrical energy. This possibility of use is justified by biogas properties, which make it convenient for IC engines.

India is largest cattle breeding country; there is abundance of raw material for producing biogas. Also municipal wastes & kitchen wastes can be used for this purpose. The use of methane (CH_4) separated from biogas as a fuel will substantially reduce harmful engine emission and will help to keep the environment clean. Biogas consists of approximately 50-70 % methane. It is economical and slurry can be used as organic manure. In 1981 an effort has been made to use biogas in a converted compression ignition (CI) engine to spark ignition (SI) engine by D. J. Hickson. He experienced 35% less power compared to diesel and 40% less compared to gasoline fuel. In that year another research was done by S. Neyeloff and W. W. Cunkel. They used a CFR engine and ran it with simulated biogas in different compression ratios. They reached to compression ratio of 15:1 for optimal solution. The lower heating value, corrosive composition and difficulties in transportation of the fuel were main challenges for biogas. In 1983, R.H. Thring concluded that biogas would be attractive just where it is close to production site and he suggested converting gaseous fuels like biogas or natural gas to liquid fuels such as methanol or gasoline.

II. BIOGAS AS FUEL FOR C.I ENGINES

2.1 Production of biogas-

Biogas is produced by extracting chemical energy from organic materials in a sealed container called a digester. The generation of biogas is the concept of Anaerobic Digestion (AD), also called biological gasification. It is a naturally occurring, microbial process that converts organic matter to methane (CH_4) and carbon dioxide (CO_2). The chemical reaction takes place in the presence of methanogenic bacteria with water an essential medium in the absence of oxygen to produce methane.

2.2 Composition of biogas-

The general composition of biogas is methane (CH_4), carbon dioxide (CH_4), hydrogen (H_2), nitrogen (N_2), water vapour (H_2O) and traces of hydrogen sulphide (H_2S) Table-1

Table-1 Composition of biogas

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

Source (Karki et al, 2005)

2.3 Storage of biogas-

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 (Table-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.

Table-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*10^5 KPa)	**Commercial gas Cylinders**	**Alloy steel**

2.4 Properties of Biogas used as Fuel in C.I Engines-

Biogas contains 50% to 70% of CH_4, 5-10 % of H_2 and up to 30 -40 % of CO_2. After being cleaned of carbon dioxide, this gas becomes a fairly homogeneous fuel containing up to 80 % of methane with the calorific capacity of over 25 MJ/m³. The most important component of biogas, from the calorific point of view, is methane. The other components are not involved in combustion process, and rather absorb energy from combustion of CH_4 as they leave the process at higher temperature than the one they had before the process. Requirements to remove gaseous components depending on the biogas utilization are in Table-3. (Hingerl, 2001).Thermodynamic properties of CH_4 are in Table-4.

Table-3 Requirements to remove gaseous components depending on the biogas utilization

Application	H_2S	CO_2	H_2O	Siloxane
CHP Engine	**<500 ppm**	**No**	**No condensation**	**Yes**
Vehicle fuel	**Yes**	**Recommended**	**Yes**	**No**

Table-4 Thermodynamic properties of CH_4

Properties	Values
Specific heat(Cp)	**2.165 kJ/kgK**
Molar mass(M)	**16.04 kg/kmol**
Density (ρ)	**0.72 kg/m³**
Individual gas constant (R)	**0.518 kJ/kgK**
Lower calorific value(Hu) (Hu, n)	**50000 kJ/kg 36000 kJ/ m³n**

2.4.1 Properties of Biogas for Engine Performance-

The actual calorific value of biogas is function of the CH_4 percentage, the temperature and the absolute pressure, all of which differ from case to case. The actual calorific value of biogas is a vital parameter for the performance of an engine. The fuel consumption of CI engine using biogas is often specified in m^3n/h or m^3n/kWh. The standard cubic meter (m^3n) means a volume of 1 cubic meter of gas under standard conditions (273K and 10132 Pa). The consumption of biogas in actual volume will differ from these data according to the actual conditions of biogas fed to the engine in terms of temperature, pressure and CH_4 content. Determining of actual biogas consumption is vital for dimensioning the engine.

2.4.2 Technical Parameters of Biogas for Engine Performance-

Technical parameters of biogas are very important because of their effect on the combustion process in an engine. Those properties are:-

→ Ignitability of CH_4 in mixture with air: CH_4: 5...15 Vol. %, Air: 95...85 Vol. %

→Combustion velocity in a mixture with air at p = 1 bar: cc = 0.20 m/s at 7% CH_4, cc = 0.38 m/s at 10% CH_4

→The combustion velocity is a function of the volume percentage of the burnable component, here CH_4. The highest value of cc is near stoichiometric air/fuel ratio, mostly at an excess air ratio of 0. 8 to 0.9. It increases drastically at higher temperatures and pressures.

→ Temperature at which CH_4 ignites in a mixture with air Ti = 918K ... 1023 K

→Compression ratio of an engine, 'e' at which temperatures reach values high enough for self-ignition in mixture with air(CO_2 content increases possible compression ratio) e = 15...20

→Methane number, which is a standard value to specify fuel's tendency to knocking (uneven combustion and pressure development between TDC and BDC). Methane and biogas are very stable against knocking and therefore can be used in engines of higher compression ratios than petrol engines.

→Stoichiometric air/fuel ratio on a mass basis at which the combustion of CH_4 with air is complete but without unutilized excess air.

2.5 Problems to use Biogas in C.I Engines-

→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.

→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 ($Fe_2 0_3$ -rusty nails are a good source) or zinc oxide (ZnO). These materials can be re-generated on exposure to the air, although the smell of H_2S is unpleasant.

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

→The gas can vary in quality and pressure.

III. PURIFICATION OF BIOGAS FOR C.I ENGINES

3.1 Removal of CO -

CO_2 is high corrosive when wet and it has no combustion value so its removal is must to improve the biogas quality. The processes to remove CO_2 are as follows

a) Caustic solution, NAOH- 40% NAOH + CO_2 = $NAHCO_3$

b) Refined process, K_2CO_3 - 30 % K_2CO_3 + CO_2 = $2KCO_3$

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.

3.2 Removal of H□S -

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.

A purity of 100% CH_4 can be obtained by a pressurized water scrubbing tower with counter current. A reduction of CO_2 from 30% to 2% in biogas is achieved, when the gas flow rate was 1.8m³/h at 0.48 bar pressure and water flow rate was of 0.465m³/h in a continuous counter current type scrubber. Compressed biogas at 5.88 bar pressure while passed through a 6 m high scrubbing tower at a flow rate of 2m³/h gives 87.6% removal of CO_2. Solid membrane of acetate-cellulose polymer has permeability for CO_2 and H_2S is 20 to 60 times greater than CH_4, when the biogas flow pressure is maintained at 25-40 bar. Generally the membrane permeability is <1 mm. For higher methane purity the permeability must be high. Monsanto and acetate cellulose membranes give best separation to CO_2, O_2 and H_2S than CH_4 when temperature and pressure was maintained at 25℃ and 5.50 bar respectively. Naturally occurred solid Zeolite-Neopoliton Yellow Tuff (NYT) can absorb 0.4 kg of CO_2 per kg of chabazite at 1.50 bar and 22°C. During this adsorption process H_2S content is removed out.

IV. BIOGAS IN C.I 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. Diesel engines require combination of biogas and diesel oil for combustion. 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. After removal of impurities it is compressed in a three or four stage compressor up to a pressure of 20 MPa and stored in a gas cascade, which helps to facilitate quick refueling of cylinders. If the biogas is not compressed than the volume of gas contained in the cylinder will be less hence the engine will run for a short duration of time.

4.1 Biogas in Diesel Engine Application-

Biogas generally has a high self-ignition temperature hence; it cannot be directly used in a CI engine. So it is useful in dual fuel engines. The dual fuel engine is a modified diesel engine in which usually a gaseous fuel called the primary fuel is inducted with air into the engine cylinder. This fuel and air mixture does not auto ignite due to high octane number. A small amount of diesel, usually called pilot fuel is injected for promoting combustion. The primary fuel in dual fuelling system is homogeneously mixed with air that leads to very low level of smoke. Dual fuel engine can use a wide variety of primary and pilot fuels. The pilot fuels are generally of high cetane fuel. Biogas can also be used in dual fuel mode with vegetable oils as pilot fuels in diesel engines. Introduction of biogas normally leads to deterioration in performance and emission characteristics. The performance of engine depends on the amount of biogas and the pilot fuel used. Measures like addition of hydrogen, LPG, removal of CO_2 etc. have shown significant improvements in the performance of biogas dual fuel engines. The ignition delay of the pilot fuel generally increases with the introduction of biogas and this will lead to advance the injection timing. Injectors opening pressure and rate of injection also are found to play important role in the case of biogas fuelled engine, where vegetables oil is used as a pilot fuel. The CO_2 percentage in biogas acts as diluents to slow down the combustion process in Homogenous charged compression ignition (HCCI) engines. However, it also affects ignition. Thus a fuel with low self-ignition temperature could be used along with biogas to help its ignition. This kind of engine has shown a superior performance as compared to a dual fuel mode of operation.

4.2 Biogas in Dual Fuel Engine Application-

In this case, the normal diesel fuel injection system still supplies a certain amount of diesel fuel. The engine however sucks and compresses a mixture of air and biogas fuel which has been prepared in external mixing device. The mixture is then ignited by and together with the diesel fuel sprayed in. The amount of diesel fuel needed for sufficient ignition is between 10% and 20% of the amount needed for operation on diesel fuel alone. Operation of the engine at partial load requires reduction of the biogas supply by means of a gas control valve. A simultaneous reduction of airflow would reduce power and efficiency because of reduction of compression pressure and main effective pressure. So, the air/fuel ratio is changed by different amounts of injected biogas. All other parameters and elements of diesel engine remain unchanged.

4.2.1 Modification of Diesel Engine into Dual Fuel Engine-

Advantages

→Operation on diesel fuel alone is possible when biogas is not available.

→ Any contribution of biogas from 0% to 85% can substitute a corresponding part of diesel fuel while performance remains as in 100% diesel fuel operation.

→Because of existence of a governor at most diesel engines automatic control of speed/power can be done by changing the amount of diesel fuel injection while the biogas flow remains uncontrolled. Diesel fuel substitutions by biogas are less substantial in this case.

Limitations

→The dual fuel engine cannot operate without the supply of diesel fuel for ignition.

→The fuel injection jets may overheat when the diesel fuel flow is reduced to 10% or 15% of its' normal flow. Larger dual fuel engines circulate extra diesel fuel through the injector for cooling.

→To what extent the fuel injection nozzle can be affected is however a question of its' specific design, material and the thermal load of the engine, and hence differs from case to case.

→A check of the injector nozzle after 500 hours of operation in dual fuel is recommended.

4.2.2 Performance and Operation Parameters-

The performance of diesel gas engines in dual fuel mode has been found o be almost equal to the performance using diesel fuel alone as long as the calorific value of biogas is not too low. The inlet channel and manifold of diesel engine are dimensioned in such a way that at the maximum speed and power output of the engine sufficient air can be sucked in to obtain an air/diesel fuel ratio, which is optimal for operation at this point. When the diesel fuel is reduced and an air/biogas mixture is sucked instead of air alone, part of the air is replaced by biogas. With less air fed to the engine ad an excess air ratio necessarily maintained at $\lambda = 1,2...1,3$ the total fuel input will be less than the fuel input in diesel operation. As a result in this reduction in both air and fuel, the maximum power output at high speed in dual fuel mode may be less than in diesel fuel operation. This decrease is less significant than in modified petrol engines. For operation in medium and low speeds the air inlet is larger than necessary and allows a relatively larger amount of air/fuel mixture to be sucked in. Hence the power output will not be significantly lower than in diesel operation.

4.3 Biogas in HCCI Engine Application-

The Homogeneous Charge Compression Ignition (HCCI) concept is a potential for achieving a high thermal efficiency and low Nitrogen Oxide (NO) emission. The HCCI engine with 50 % biogas as a primary fuel and 50% diesel as pilot fuel gives a maximum NO of 20 ppm is a major advantage over biogas diesel dual fuel mode. In biogas diesel dual fuel mode the presence of CO_2 in biogas lowers the thermal efficiency however, in biogas diesel HCCI (BDHCCI) mode CO_2 reduces high heat release rate. The break mean effective pressure (BMEP) in BDHCCI mode is in the range of 2.5 bar to 4 bar. The smoke and Hydro Carbon (HC) level were also low when the biogas is used as a primary fuel for BDHCCI mode. For HCCI operation the inducted charge temperature is required to be maintained at 80-135°C, which can be obtained from the exhaust heat. Thus biogas with HCCI engine gives high efficiency and low emission.

V. EXHAUST EMISSION

The exhaust emission contains three specific substances which contribute the air pollution, hydrocarbon, carbon monoxide & oxides of nitrogen. Hydrocarbons are the unburned fuel vapour coming out with the exhaust due to incomplete combustion. Hydrocarbon also occurring in crankcase by fuel evaporation. The emission of hydrocarbon is closely related to many design &operating factors like induction system, combustion chamber design, air fuel ratio, speed, load. Lean mixture lower hydrocarbon emission. Carbon monoxide occurs only in engine exhaust. It is the product of incomplete combustion due to insufficient amount of air in air- fuel mixture. Some amount of CO is always present in the exhaust even at lean mixture. When the throttle is closed to reduce air supply at the time of starting the vehicle, maximum amount of CO is produced. Oxides of nitrogen are the combination of nitric oxide & nitrogen oxide &availability of oxygen are the two main reasons for the formation of oxides of nitrogen. With biogas, co emission levels are low than that of gasoline.

VI. CONCLUSION

The study concludes the biogas production from organic wastes, its' composition and properties for use in C.I Engines. Different techniques for CO_2, H_2S scrubbing are discussed, among which water scrubbing is a simple continuous and cost effective method for purification. Attention is also focused for making biogas as alternate fuel in Diesel Engines and dual fueling is recommended to be the best one for biogas CI operation. Drop of CO_2 in biogas for dual fueling increases the thermal efficiency. In biogas HCCI mode, the presence of CO_2 controls the high heat release rate; hence the durability of engine components will not be affected. Therefore it is recommended to use biogas as alternate fuel in C.I engines.

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