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Theoretical Investigation: Biogas As An Alternate Fuel For IC Engines

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ABSTRACT

In the present world there are over a billion of Automobiles and in which most of the fuel being used are fossil fuels. To eliminate the harmful effects being caused by the fossil fuels there is a need for alternate fuels. One of an alternate fuel is biogas which is a mixture of gases produced by the breakdown of organic matter in the absence of oxygen. It can be produced from regionally available raw materials such as recycled waste. It is mainly composed of methane and carbon dioxide. Biogas will give lower exhaust emissions than fossil fuels, and so help to improve local air quality. The paper sets out the resource that is available for producing biogas, together with the basic details of production technology and the methods available for purification of it to be used as vehicular fuel. It goes on to explore how this gas can be used in vehicles, describing the basic technology requirements. It gives us the basic outline of the modifications to be made in the present engines and storage of it on the vehicles.

Keywords: Biogas, IC Engine, Anaerobic Digestion

INTRODUCTION

Biogas typically refers to a mixture of gases produced by the breakdown of organic matter in the absence of oxygen. It is a renewable energy source and in many cases exerts a very small carbon footprint. This renewable energy is already used for heat and electricity production, but the best upgrading solution of this clean energy should be the production of vehicle fuel. Biogas is worth using rather than natural gas because of its renewable sources. The fossil resources of oil, gas and coal are limited and also cause harmful effects to the environment. One effective way to avoid these problems is the biogas, which is produced by the fermentation of animal dung's, human sewage or agricultural residues, is rich in methane and has the same characteristics as the natural gas.

PRODUCTION OF BIOGAS

Biogas, which is mainly composed of methane and carbon dioxide, is produced during the decomposition of organic matter in anaerobic conditions. The organic matter is decomposed in a number of steps in collaboration between several different types of microorganisms. The efficiency of the biogas production depends on how suitable the conditions are for the microorganisms. To initiate a biogas process, sludge containing the bacteria for starting the process is inoculated from an existing biogas plant.

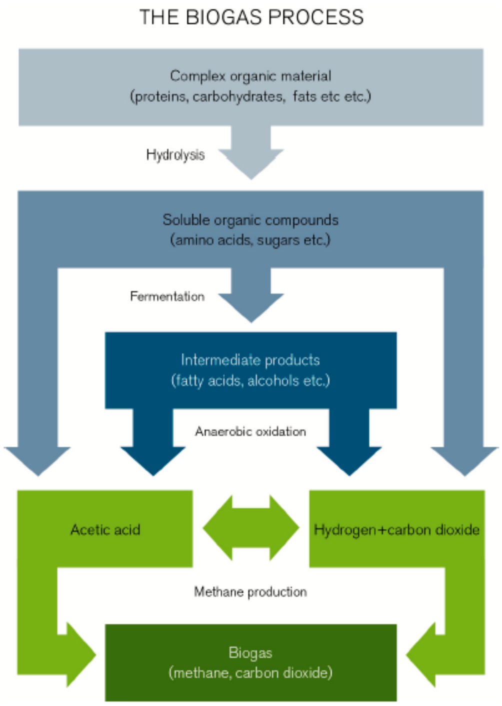

FIG: 1 STEPS INVOLVED IN ANAEROBIC DIGESTION

BIOGAS PRODUCTION FOR DIFFERENT SUBSTRATES

The biogas production varies between different substrates depending on the composition of the substrate. The biogas production figures in the table below are determined in laboratory scale and therefore higher than expected during continuous operations in full scale.

TABLE: 1 BIOGAS PRODUCTION FOR DIFFERENT SUBSTRATES

Substrate	Biogas production		Methane Concentration
	[m^3/ton TS]	[m^3/ton wet weight]	%
Sludge from waste water treatment plants	300	15	65
Fish waste	1279	537	71
Straw	265	207	70
Stored food waste	618	204	63
Liquid cattle manure	244	22	65
Potato halum	453	68	56
Slaughter house waste	275	92	63
Liquid pig waste	325	26	65

COMPOSITION OF BIOGAS

During anaerobic digestion (i.e. digestion in the absence of oxygen) organic material is broken down in several steps by different types of microorganisms. The end-products are a gas containing mainly methane and carbon dioxide, referred to as biogas; and slurry or solid fraction consisting of what is left of the treated substrate, referred to as digestate. The composition of biogas varies depending upon the origin of the anaerobic digestion process. Landfill gas typically has methane concentrations around 50%. Advanced waste treatment technologies can produce biogas with 55%–75% methane, which for reactors with free liquids can be increased to 80%-90% methane using in-situ gas purification techniques.

TABLE: 2 Composition of Biogas

Compound	Molecular formula	%
Methane	CH4	50–75
Carbon dioxide	CO	25-50
Nitrogen	N2	0-10
Hydrogen	H2	0-1
Hydrogen Sulphide	H2S	0-3
Oxygen	O2	0-0
Water Vapour	H2O	Traces

PURIFICATION OF BIOGAS

Biogas apart from methane and carbon dioxide it also contains hydrogen sulphide, water vapour and nitrogen. From that mixture hydrogen sulphide and carbon di oxide have to be removed so as to be used as a vehicular fuel.

TABLE: 3 REQUIREMENT OF PURIFICATION

Application	H_2S removal	CO_2 removal	H_2O removal
Gas Heater (Boiler)	< 1000 ppm	No	No
Kitchen Stove	Yes	No	No
Stationary Engine(CHP)	< 1000 ppm	No	No Condensation
Vehicle Fuel	Yes	Recommended	Yes
Natural Gas Grid	Yes	Yes	Yes

Methods of purification:
There are six methods available to remove carbon di oxide and hydrogen sulphide from the biogas.

❖ **Scrubbing:**
It is a process used to remove $CO_2$and $H_2S$from the mixture of gases. The absorption process is purely physical. Biogas is pressurized and fed to the bottom of a packed column and water is fed on the top and so absorption process is operated counter-currently. Water scrubbing can be used for selective removal of H_2S since H_2S is more soluble than CO_2in water. Water which exits the column with absorbed CO_2 and/or H_2S can be regenerated and re-circulated back to the scrubber. Regeneration is accomplished by de-pressuring or by stripping with air in a similar column. Stripping with air is not recommended when high levels of H_2S are handled since water quickly becomes contaminated with Sulphur which causes operational problems.

Advantages:
- No special chemicals required (except relatively inexpensive PEG) and removal of both $CO_2$and H_2S.

Disadvantages:
- Requires a lot of water even with regeneration
- Limitations on H_2S removal, because the CO_2decreases pH of the solution
- Corrosion to the equipment caused by H_2S.

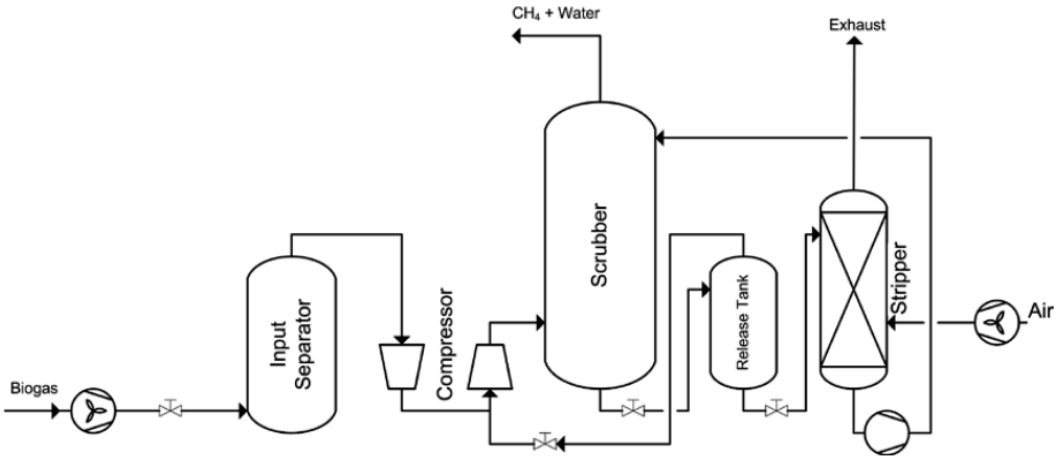

FIG: 2 SCRUBBING

❖ **Chemical Adsorption:**

Chemical absorption involves formation of reversible chemical bonds between the solute and the solvent. Regeneration of the solvent, therefore, involves breaking of these bonds and correspondingly, a relatively high energy input. Chemical solvents generally employ either aqueous solutions of amines (i.e. mono-, di-or tri-ethanolamine) or aqueous solution of alkaline salts (i.e. sodium, potassium and calcium hydroxides).

Advantages:

- Complete H2S removal.
- High efficiency and reaction rates compared to water scrubbing.
- Ability to operate at low pressure.

Disadvantages:

- Additional chemical inputs needed.
- Need to treat waste chemicals from the process.

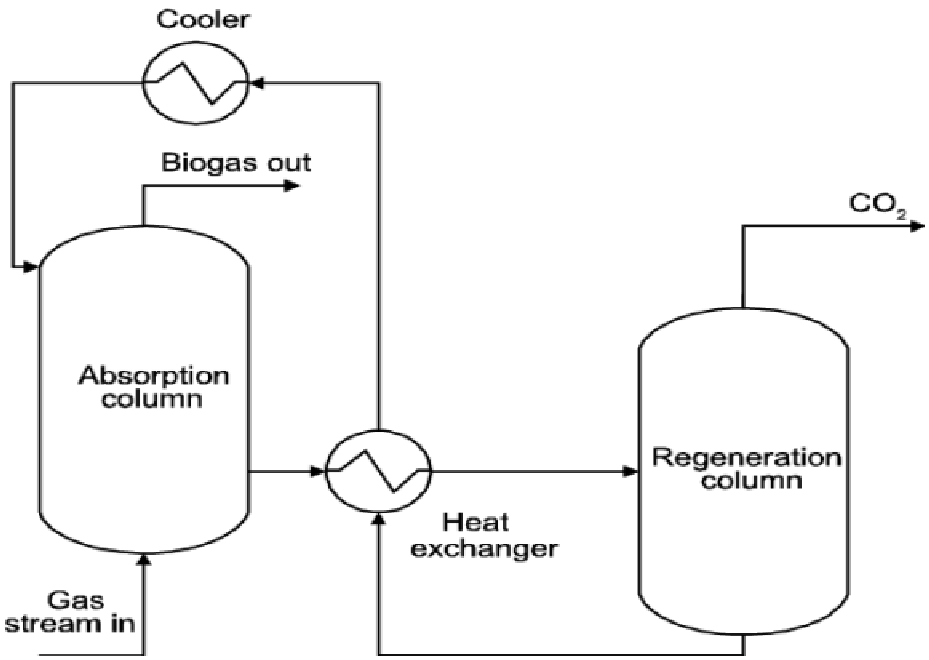

FIG: 3 CHEMICAL ADSORPTION

❖ **Pressure swing adsorption:**

Used to separate some gas species from a mixture of gases under pressure according to species' molecular characteristics and affinity for an adsorbent material Operates at near-ambient temperatures and so differs from cryogenic distillation techniques of gas separation. Special adsorptive materials (zeolites and GAC) are used as a molecular sieve, preferentially adsorbing the target gas species at high pressure. Process then swings to low pressure to desorb the adsorbent material

Advantages:

- More than 97% CH4 enrichment.
- Low power demand.
- Removal of nitrogen and oxygen.

Disadvantages:

- Additional H2S removal step is needed before PSA.
- Tail gas from PSA still needs to be treated.
- Relatively expensive.

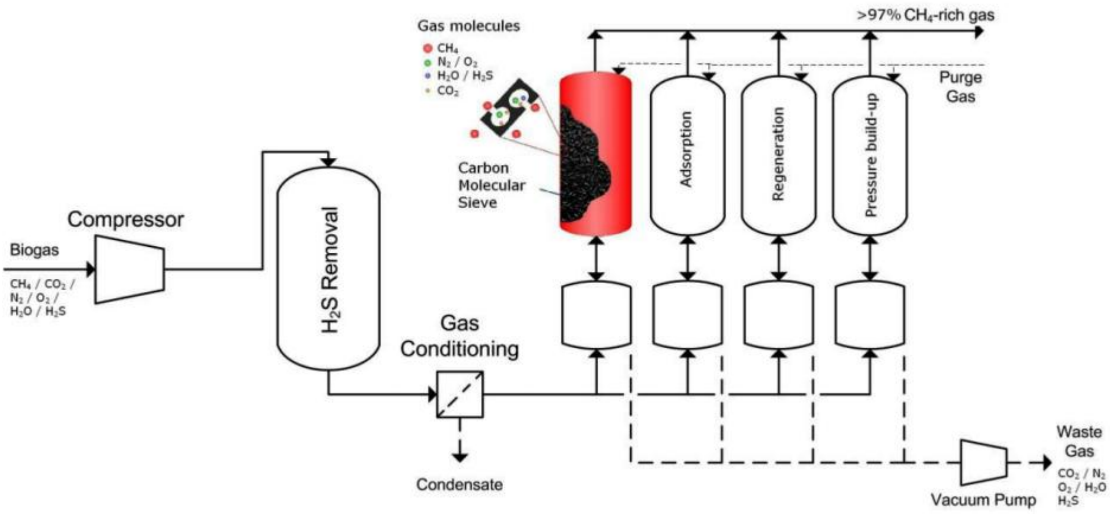

FIG: 4 PRESSURE SWING ADSORPTION

❖ **Membrane Purification:**

Some components of the raw gas are transported through a thin membrane while others are retained. The permeability is a direct function of the chemical solubility of the target component in the membrane. Solid membranes can be constructed as hollow fiber modules which give a large membrane surface per volume and thus very compact units. Operating pressures are in the range of 25-40 bars. There are 2membrane separation techniques: high pressure gas separation and gas-liquid adsorption. The high pressure separation process selectively separates H2S and CO2from CH4. Usually, itis performed in three stages and produces 96% pure CH4. Gas liquid adsorption is a newly developed process that uses micro-porous hydrophobic membranes as an interface between gas and liquids. The CO2and H2S dissolve into the liquid while the methane (which remains a gas) is collected for use.

Advantages:

- Compact and light in weight.
- Low energy and maintenance requirements.
- Easy processing.

Disadvantages:

- Relatively low CH4yield and high membrane cost.

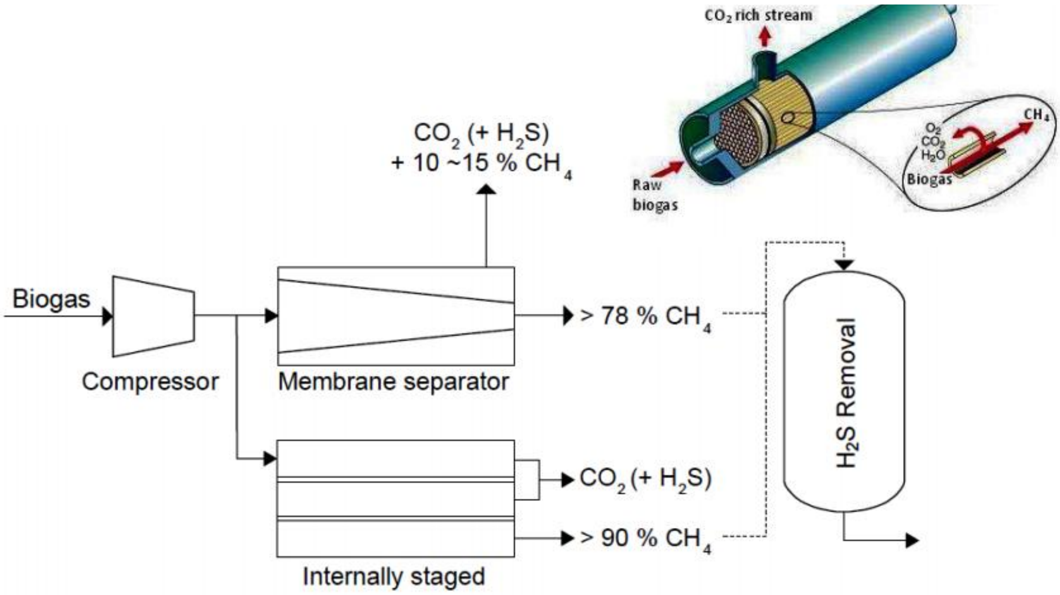

FIG: 5 MEMBRANE PURIFICATION

❖ **Cryogenic separation:**

CO2, H2S and all other biogas contaminants can be separated from CH4, because each contaminant liquefies at a different temperature-pressure domain. It operates at low temperatures, near -100oC, and at high pressures, almost 40 bars. Operating requirements are maintained by using a linear series of compressors and heat changers. Finally, the distillation column separates CH4from the other contaminants, mainly H2S and CO2

Advantages:

- High purity of the upgraded biogas (99% CH4).
- Large quantities can be efficiently processed.

Disadvantages:

- Use of considerable process equipment, mainly compressors, turbines and heat exchangers.
- Higher capital and operating costs relative to others.

❖ **Biological processes:**

It is widely employed for H2S removal. Chemical use is limited. Use of chemotropic bacterial species (*Thiobacillusgenus*) to condition biogas is well established. Chemotrophic thio bacteria can purify H2S in both aerobic and anaerobic pathways. Most thio bacteria are autotrophic, consuming CO2and generating chemical energy from the oxidation of reduced inorganic compounds such as H2S. SO42−and S0 are produced as waste products. Biogas, which contains around 30% CO_2, is a good source of inorganic carbon, rendering it more suitable for autotrophic bacteria. Under limited oxygen conditions, *Thiobacillus* bacteria evoke a redox-reaction which produces S^0. Conversely, an excess oxygen condition will lead to SO_4^{2-}generation and, thus, acidification

USES OF BIOGAS

- ➢ Production of Heat& Steam.
- • Electricity Production
- • Internal Combustion
- • Gas Engines
- • Fuel Cells
- ➢ Vehicle Fuel.
- ➢ Production of Chemicals.

BIOGAS AS VEHICULAR FUEL

Biogas is the product of fermentation of man and animals' biological activity waste products when bacteria degrade biological material in the absence of oxygen, in a process known as anaerobic digestion. Biogas contains 50% to 70% of CH_4, 2 % of H_2 and up to 30 % 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, CH_4. 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.

Thermodynamic properties of CH_4 at 273 K and 101325 Pa are:

- ➢ specific heat c_p = 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 H_u = 50000 kJ/kg

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. %

Mixtures with less than 5 Vol. % and mixtures with more than 15 Vol.% of CH_4 are not properly ignitable with spark ignition.

- ➢ Combustion velocity in a mixture with air at p = 1 bar:
  c_c = 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.

- 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. Methane and biogas are very stable against knocking ad 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 and carbon dioxide it is a renewable fuel produced from waste treatment.

MODIFICATIONS TO BE MADE IN THE PRESENT ENGINES

THE GAS DIESEL ENGINE

Diesel engines can be modified to operate on biogas in two different ways:

I. Dual fuel operation with ignition by pilot fuel injection.
II. Operation on gas alone with spark ignition.

❖ THE DUAL FUEL ENGINE:

The normal diesel fuel injection system still supplies a certain amount of diesel fuel. The engine 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. Modification of diesel engine into dual fuel engine has the following advantages: Operation on diesel fuel alone is possible when biogas is not available.

There are certain 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 it's normal flow.

❖ AS GAS OTTO ENGINE:

This modification involves a major operation on the engine and the availability of certain parts, which will have to be changed. These alterations are:

- Removal of the injector pump and injector nozzles.
- Reduction of the compression ratio to ε = 10...12.
- Mounting of an ignition system with distributor (cum angular gear), ignition coil, spark plugs and electric supply (alternator).

- Provision of a mixing device for the supply of an air/fuel mixture with constant air/fuel ratio.

THE GAS OTTO ENGINE

The modification of an Otto engine is comparatively easy as the engine is designed to operate on an air/fuel mixture with spark ignition. The basic modification is the provision of an air/gas mixer instead of carburetor. The engine control is performed by the variation of the mixture supply. An increase in compression ratio appears to be desirable as it provides an increase of the process from the thermo-dynamical point of view.

STORAGE OF BIOGAS ON VEHICLES

The utilization of biogas in vehicles requires a method of compact storage to facilitate the independent movement of the vehicle for a reasonable time. Larger quantities of biogas can only be stored at small volumes under high pressure, e.g. 200 . . .300 bar, or purified as methane in a liquid form at cryogenic conditions, i.e. -161 °C and ambient pressure. The processing, storage and handling of compressed or liquefied biogas demand special and costly efforts. Compression is done in reciprocating gas compressors after filtering of H2S. Intermediate cooling and removal of the humidity in molecular sieve filters are essential as the storage containers should not be subjected to corrosion from inside. Purification of biogas to CH4 increases the storage efficiency by 25 to 30% but involves an extra gas washing column in the process. Liquefaction of biogas requires drying and purification to almost 100% CH4 in one process and an additional cryogenic process to cool the CH4 down to -161°C where it condenses into its liquid form. Storage is optimal at these conditions as the volume reduction is remarkable, i.e. 0.6 m^3n with an energy content of 6 kWh condense to one lifer of liquid with an energy equivalent of 0.61 diesel fuel. The required tank volume is only 1.7 times the volume needed for diesel fuel. This advantage is opposed by a more sophisticated multistage process, the handling of the liquid in specially designed cryo-tanks with vacuum insulation and the fact that for longer storage it has to be kept at its required low temperature in order to prevent evaporation. This requires additional energy and equipment.

CONCLUSION

An alternative fuel for IC Engines has been presented: Biogas, which is a renewable source of energy and leaves a very little carbon foot print. The changes that have to be made in the present engines to use biogas as a fuel are being discussed. The Biogas contains not only methane but also other gases such as carbon di oxide, hydrogen sulphide which have to be purified from the biogas. By the use of biogas as fuel there is a decrease in about 20-30% of carbon emission compared to other fossil fuels. For biogas the reduction of green house gas emissions can be as much as 100 %. In fact, a reduction above 100 % can be achieved when biogas produced from manure is utilized as a vehicle fuel. Methane, which is a strong green house gas, is released into the atmosphere from manure in traditional manure storage. Biogas as a vehicle fuel can thus both decrease the leakage of methane from manure and decrease the emissions of fossil carbon dioxide. Another advantage is that vehicles running on upgraded biogas or natural gas have lower emissions of particles, NOx and SOx.

REFRENCES

- **Books:**

1. Biogas for IC Engines - Klaus von Mitzlaff
2. Biogas plants – Ludwig Sasse
3. Handbook of air pollution from internal combustion engines – Pollution Formation and control
4. John B. Heywood: "Internal Combustion Engine Fundamentals”

- **Publications:**

1. Swedish Gas Technology Centre: Basic Data on Biogas
2. Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas in California

- **Websites:**

1. http://www.iea-biogas.net
2. http://www.biogaspro.com