Production of Biogas from Multiple Feedstocks and its Application as a Fuel for Spark Ignition Engines - A Review

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INTRODUCTION

The enormous growth in industries and an increase in population is the main reason for the heavy depletion of fossil fuel. Owing to the current energy scenario, the entire world is looking alternate to fossil fuels that should be renewable ones. Gaseous fuels are widely used nowadays because of their wide ignition limits and also have the capability to form a uniform mixture which reduces pollution. Various alternative gaseous fuels are compressed natural gas, liquefied petroleum gas, hydrogen, biogas, producer gas. Among all the renewable energy sources, biogas is particularly significant because of possibility of use in internal combustion engines (Mustafi et al., 2008), which are the main power source for transport sectors and also biogas is become more popular in rural areas for cooking and is produced from cow dung, other animal wastes and also from plant wastes by anaerobic decomposition. It is also known as gobar gas. Biogas is used as an alternative fuel in petrol engine and dual fuel in the diesel engine. Biogas is primarily composed of methane (CH₄), carbon dioxide (CO₂), hydrogen (H₂), nitrogen (N₂) and minute impurities like hydrogen sulphide (H₂S). Biogas can be subjected to clean by removal of impurities by scrubbing process. It is made up of two-third methane and remaining by carbon dioxide by volume. Biogas is safer in many aspects compared to other fuels. Ignition temperature for biogas is higher compared to gasoline and diesel fuel, which reduces ignition delay and makes it less hazardous. Biogas can be upgraded to synthetic gas by Removal of CO₂ is necessary to increase the density and calorific value of the gas to meet quality (Qian et al., 2017). An attempt was made by a researcher to a covert diesel engine to SI engine fueled by biogas and an observed 35% and 40% less power compared to diesel and gasoline fuel respectively (Dobshaw et al., 2019). Inconsequent with another study was done by Neyloff and Cunkel (1981) in a Cooperative Fuel Research (CFR) engine fuelled with simulated biogas in different compression ratios. They have noted storing and transportation were main challenges for biogas. Thring (1985) concluded that biogas would be glowing appearance just where it is close to the production site. This review paper is covered the potential biogas production and its application as a fuel in IC engines. The objective of this review is to make a simple for the researcher to do future development.

BIOGAS PRODUCTION

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. Raw materials mostly used for biogas production
are cow dung, sewage, crop residues, vegetable wastes, poultry droppings and pig manure. Biogas is produced by hydrolysis, acidogenesis, acetogenesis, methanogenesis. Various types of biogas plants based on design are

- Fixed dome plant
- Floating drum plant
- Low cost polyethylene tube digester
- Balloon plants
- Horizontal plants
- Earth pit plants
- Ferrocement plants

Experimental purpose the floating drum type is most commonly used to produce biogas in India. The Floating drum type plant is shown in **Figure 1**.

It consists of airtight container made of steel or brick masonry is called a digester with inlet and outlet for raw material feeding and getting manure respectively. Another drum is called floating drum which floats over fixed digester employing rope and weight through the pulley. It has an opening at the top as a gas outlet. The ideal temperature for the production of biogas is 30° to 40°C and the required pH will be 6 to 8. Inhibitors can also be used to produce methane like ammonium sulfate. In case of cow dung as a feedstock for biogas production, cow dung is mixed with water in 3:1 ratio and fed to the digester through an inlet and set up is placed in an open atmosphere and exposed to sunlight. After two or three weeks, cow dung is digested to yield biogas. The biogas main constituent and their percentage are listed in **Table 1**. Some important thermodynamic properties of biogas are listed in **Table 2**.

### Figure 1. Schematic diagram of floating drum type plant for biogas production

### Table 1. Biogas composition

| Composition     | Molecular Formula | Percentage |
|-----------------|-------------------|------------|
| Methane         | CH₄               | 50-75      |
| Carbon dioxide  | CO₂               | 25-50      |
| Nitrogen        | N₂                | 0-10       |
| Hydrogen        | H₂                | 0-1        |
| Hydrogen sulphide| H₂S              | 0-3        |

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| Hydrogen sulphide| H₂S              | 0-3        |
Table 2. Biogas Fuel Properties

| Property                     | Value          |
|------------------------------|----------------|
| Molecular Weight             | 24-29          |
| Density (kg/L, 15 °C)        | 0.96-1.17 kg/m³|
| Specific Gravity (15 °C)     | 0.94-0.98      |
| Boiling point                | 300 °C         |
| Specific Heat                | 1.6 KJ/kg.k    |
| Individual Gas constant R    | 0.518 KJ/kg.K  |
| Latent Heat of Vaporization  | 481 KJ/kg      |
| Lower Heating Value          | 21570 KJ/m³    |
| Higher Heating value         | 23000 KJ/m³    |
| Autoignition Temperature,    | 600-650 °C     |
| Octane Number                | 130            |
| Boiling point                | -161.5 °C      |

Table 3. Biogas as a fuel in dual fuel CI engine

|Investigators, Year            | Engine Specification          | Biogas Production Performance Results                                                                 | Emission Results                                                                 |
|-------------------------------|-------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Jagadish and Guntapure, 2019  | Single cylinder, four-stroke | Simulated biogas (different mixtures of methane-enriched biogas)                                        | The brake thermal efficiency is lower by 2.43% and the cylinder peak pressure is  |
|                               | constant speed, direct injection, water-cooled diesel engine |                                                                                                           | higher by 6.55% for dual fuel mode when compared with diesel mode.                |
| Ambarita al. et al., 2017     | Tiger Diesel Engine R175 AN | Simulated biogas (mixing of natural gas and CO₂)                                                        | Output power and efficiency increases with increasing engine speed and SFC         |
|                               |                               |                                                                                                           | decrease.                                                                        |
| Prajapati et al., 2015        | Single cylinder diesel engine | Biodegradable material                                                                                   | BSFC is high with an increase in load but TE decreases.                          |
| Bora et al., 2014             | 3.5kW VCR diesel engine      | Organic matter                                                                                           | Emissions of CO₂, CO and HC increase with increasing load.                       |
|                               |                               |                                                                                                           | At 100% load, BTE was 20.04% at compression ratio is 18.                          |
|                               |                               |                                                                                                           | Reduction in CO and HC by 26.22% and 41.97% when CR increased from 16 to 18 but there is an increase in NOₓ by 66.65%. |
| Barik and Murugan, 2014       | Single-cylinder direct injection diesel engine | Anaerobic digestion of Pongamia pinnata seed cakes                                                      | The biogas flow rate of 1.2 kg/h shows a higher brake specific energy consumption (BSEC) of 51.8 MJ/kWh at higher energy share of 60%, at 25% load ignition delay. |
|                               |                               |                                                                                                           | At full load, NO and smoke emissions were found to be lower by about 34% and 14% with long load.            |
| Gomez-Montoya et al., 2013    | Two-cylinder diesel engine    | Organic waste                                                                                           | Thermal energy increases up to 16% at full load                                    |
|                               | coupled to an electric generator |                                                                                                           | CO emission decreases up to 13% at full load.                                       |
| Gomez-Montoya et al., 2010    | 3.7kW Kirloskar diesel engine | Organic waste                                                                                           | SFC decreases with an increase in power and efficiency also increases.            |
| Bari, 1996                    | Two-cylinder diesel engine    | Anaerobic fermentation of Biomass materials                                                               | Percentage of CO₂ increases, power increases and brake specific fuel consumption (BSFC) decreases. |
|                               | 16.8kW at 1500 rpm            |                                                                                                           |                                                                                  |

**BIOGAS AS A FUEL FOR CI ENGINE**

Biogas cannot be used as a substitute fuel in diesel an account of high self-ignition temperature and high Octane number. But it can be used as a primary fuel in dual fuel mode in the modified existing engine and either diesel or biodiesel as pilot secondary fuel. Modification of diesel engine into a dual-fuel engine has the following 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 (Van Ga et al., 2015). Various research on biogas as a fuel in the dual-fuel engine are listed in Table 3.

**BIOGAS AS A FUEL FOR SI ENGINE**

The use of biogas as an SI engine fuel offers several advantages. Biogas is a clean fuel causes clean combustion which results in low particulates and nitrogen oxides and reduced contamination of engine oil. The basic modification is required in SI engine is the provision of an air/gas mixer instead of the carburettor as the engine is designed to operate on an air/fuel mixture. From the previous studies conducted by Jeong et al. (2009); Arroyo et al. (2014); Kukoyi et al. (2016); Krishnaiah et al. (2017), it was noted that researchers have used both simulated biogas and direct biogas in their experimental studies. This review study has taken both cases and listed their result in Table 4 and 5.
Table 4. Biogas blends as a fuel in SI engine

| INVESTIGATORS ENGINE SPECIFICATION | BIOMAS PRODUCTION | PERFORMANCE RESULT | EMISSION RESULT |
|------------------------------------|-------------------|--------------------|-----------------|
| Park and Choi (2017)               | Water-cooled turbocharged SI engine | Biogas with added hydrogen | Maximum rise of BTE is 3.2% with boost pressure for Air fuel ratio 1.5 | NOx emission got reduced with boost pressure |
| Ayade and Latey (2016)             | 4 cylinder SI engine | Cow dung and leaves with petrol of 60%, 80% and 90% | B40 obtained maximum results in bsfc by 12% and BTE by 17% | CO and HC emission increases as gas substitution increases |
| Singh (2016)                       | 4 stroke SI engine | Biogas from Organic matter with hydrogen | BTE increases by 20% and bsfc decrease by 14% with increasing hydrogen | CO and HC level decreases by 80% and 30% and NOx increased by 13% with hydrogen addition |
| Pandya et al. (2016)               | 7.5 HP single cylinder Kirloskar engine | Methane enriched by biogas | Bsf, ME is higher than petrol but BTE was found to be low | Hydrogen substitution causes an increase in Hz results in higher NOx emission in lean combustion |
| Juntarakod (2016)                  | 3.5KW SI engine | Biogas and petrol | -- | Hydrogen substitution causes an increase in Hz results in higher NOx emission in lean combustion |
| Gohil Bhavdipsinh et al. (2016)    | 4 stroke SI engine | Biogas with methanol blend from 0/20/50% | Brake torque, BP, BTE and volumetric efficiency increases with increasing methanol but bsfc decreases | -- |
| Awogbemi et al. (2015)             | 5 HP single cylinder SI engine | Cow dung seeded with rice husk and banana peel with petrol | The high torque of 8.7Nm for biogas petrol blend at speed of 3500 rpm and BP of 311.58 kW. Mechanical efficiency increases sharply between 1000-1500 rpm and gently after that | -- |
| Chen et al. (2012)                 | Single-cylinder HONDA GX340 engine | Biomass with hydrogen and CO blended and diluted by CO2 | BMEP and BTE increases with the hydrogen addition | NOx and CO emission reduces with the increase of hydrogen concentration |
| Park et al. (2011)                 | Constant speed 6 cylinder SI engine | Biogas with added hydrogen | Maximum TE reaches at 31.1% at 80% N2 dilution | Increased N2 dilution decreases NOx level |
| Porpatham et al. (2007)            | Single-cylinder constant speed SI engine | Cow dung with hydrogen addition from 5% to 15% | Improvement in TE and power output with very lean mixtures and hydrogen concentration of 15% | HC emissions drop to 660 ppm with 10% hydrogen addition and no change in NO level |

Table 5. Biogas as fuel for SI engine

| INVESTIGATORS ENGINE SPECIFICATIONS | BIOMAS PRODUCTION | PERFORMANCE RESULT | EMISSION RESULT |
|------------------------------------|-------------------|--------------------|-----------------|
| Hotta et al. (2019) Single cylinder, variable speed (1450-1700 rpm) spark ignition engine. | Raw biogas | 18% of reduction in brake power, 66% of increase in brake specific fuel consumption and 12% of reduction in break thermal efficiency when the engine is fueled with raw biogas. | The emission components such as CO and NOx are significantly reduced by 40% and 81.5%, respectively, while, the unburnt hydrocarbon (UHC) and CO emission were increased by 6.8% and 40%, respectively. |
| Nunes de Faria et al. (2017) Single-cylinder constant speed SI engine | Biogas from organic compounds | Decrease of SFC with increasing values of equivalence ratio | Increase in equivalence ratio results in a decrease of CO and an increase in NOx |
| Kim et al. (2017) Single zone SI engine | Biogas with CO2 variations | SFC decreases with an increase in spark ignition timing | NOx, HC and CO emissions tend to increase with load |
| Samanta et al. (2016) Single zone SI engine | organic matter | BTE is 24% and BSFC is 0.29m'/Kwh at 27° BTDC spark timing | -- |
| Zhang et al. (2016) 4 stroke single cylinder SI engine with a power generator | Hydrogen-rich T-PAD (Two-Phase Anaerobic Digestion biogas) with CH4/H2/CO2 mixture | Increasing CO2 ratio decreases power output. Increasing H2/CH4 ratio increases overall TE | Increasing H2/CH4 ratio, decreases CO, HC and NOx emissions |
| Prakash et al. (2016) SkW single-cylinder SI engine | Biogas from organic material | BP for raw and upgraded biogas is 38% and 12% lower than gasoline. BSFC was lower by an average of 19.5% | CO, NOx, HC and CO2 emissions are lower for upgraded biogas than raw biogas |
| Joshi et al. (2015) 4 stroke single cylinder SI engine | Biogas from organic material | The maximum power produced is 3.3kW at 80% load. At highest load, BTE will be 42.32% | CO2 emission reduced about 60.52%. CO2 emission decreases 63.07% for Bosch type at 80% load |
| Kimura et al. (2015) SI gas engine | Low-temperature biomass gasification process from wood chips | Maximum BTE was more than 30%, even at the BMEP less than 0.4 MPa | -- |
| Przybyla et al. (2013) Petrol engine with low engine displacement | Simulated biogas and natural gas | Greater the values of ignition advance angle, higher the NOx and CO emissions | -- |
| Porpatham et al. (2013) Constant speed diesel modified SI engine | Biogas from organic matter | Increase in BTE and power output with an increase in a swirl at full throttle than part throttle | A decrease in HC level and increase in NOx emission with enhanced swirl at full throttle. |
| Porpatham et al. (2012) Diesel modified SI engine running at 1500 rpm | Cow dung | Power output with a compression ratio of 15:1 is 4.8 kW. When the compression ratio increases from 9.3:1 to 15:1, BTE increases by 26.8% | With an increase in compression ratio, NO level increases to 2650 ppm and HC to 2000 ppm |
| Huang and Crookes (1998) E6 variable compression ratio single-cylinder Spark Ignition engine | Biogas from the different mixture of domestic natural gas and CO2 | BTE reduced by 3% when CO2 increases to 40%. High power and TE obtained at compression ratio between 13:1 and 15:1 and RARF 1.05 and 0.95 | At higher compression ratio (above 13:1), higher the CO, HC and NOx emissions |
CONCLUSIONS

From the comprehensive review study in various authors findings on biogas as a fuel in the IC engine, the review study concludes the following:

- The production of biogas from various feedstock is feasible and its composition and properties are pertinent for substitute fuel in IC engines.
- The performance of diesel engines in dual fuel mode of either diesel or biodiesel and biogas is almost equal to diesel fuel operation.
- The emission characteristics of biogas fuelled SI engine are found relatively lower in particulates, carbon dioxide and nitrogen oxides emissions.
- Biogas is a very efficient, sustainable and environmental friendly fuel which helps to reduce dependence on conventional fossil fuels and the management of waste.

Finally, biogas may be recommended as an alternative fuel in CI engine.

Suggestion for Future Development

- For the long-run operation of CI engine running on biogas fuel require the following attentions
- Developing the low cost biogas purification and upgrading technologies
- During the biogas simulation, it can be enhanced by methane enrichment or the addition of hydrogen to improve its flame quality.

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