Experimental Study On Single Cylinder CI Engine Using Neat Diesel and Biogas with Varying Quantity in Dual Fuel Mode

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Abstract: ***This research work is focus on the problem of fossil fuel (Diesel) availability and its emission. Due to that we work to used renewable and locally available fuel that is Biogas. Biogas can be used as a fuel for SI as well as CI Engine. For this work we take a single cylinder four stroke diesel engine which was modified for runs in the duel fuel mode. For this experimentation biogas was injected in different quantity and obtained various performance and emission parameters like FC, BSFC, BTE, CO, CO_2, HC. . The result shows at low load condition when BG (2gm/min) added in diesel, BSFC of diesel reduces to 7.04% and when BG (8gm/min) added in diesel,BSFC of diesel reduces to 14.08%, And Also CO_2 emission is reduces to 1.196% at low load condition.***

Keywords: kitchen waste, Anaerobic Digester, Dual fuel, Biogas utilization, Biomass

1. Introduction

Due to scarcity of petroleum and coal it threatens supply of fuel throughout the world also problem of their combustion leads to research in different corners to get access the new sources of energy, like renewable energy resources. Solar energy, wind energy, different thermal and hydro sources of energy, biogas are all renewable energy resources. But, biogas is distinct from other renewable energies because of its characteristics of using, controlling and collecting organic wastes and at the same time producing fertilizer and water for use in agricultural irrigation. [1]. Energy plays a major role for the existence of mankind. Without energy, everything would come to a standstill. It is necessary to foster human development and economic growth with a secure, affordable, reliable, clean and sustainable energy supply. Today we are facing huge challenges: global warming, depleting natural resources, population growth, increasing energy demand, rising energy prices and unequal distribution of energy sources. All these factors contribute to the urgent need to transform the energy sector, which primarily depends on fossil fuels, to one that uses renewable energies and energy efficient technologies. Renewable energy is one of the key solutions to the current challenges facing by the world. Rapid extraction and fast consumption of fossil fuels have led to reduction in under-ground resources of fossil fuels. Hence the search for alternative fuels becomes a very important task for sustainable development. Bio-fuels such as bio-diesel, biogas, and bio-ethanol can provide feasible solution to the world-wide petroleum crises problems, Fossil fuel driven automobiles are the main sources of green-house gases emission. Therefore, development of alternatives of fossil fuels becomes very important task. In this study we focused on feasibility of alternative fuels in internal combustion engines. Fossil fuels reserves are limited and it will not available for long time. According to an estimate the reserves will last for 208 years for coal, 31 years for oil and 53 years for natural gas under a business scenario. The prices of crude oil keep fluctuating in daily basis. This may will be the main reason behind the growing awareness and interest for non-conventional bio-energy sources and this reduces the oil monopoly of OPEC countries. Developing country like India development of bio energy resources is very essential, because India is spending $330 million a day on imported oil and gas. And very soon India expected to be the world's third largest consumer of oil and gas. So there is an urgent need to get some alternative fuels to meet the large recruitment of oil and gas. So alternatives of these fuels such as biogas, bio- diesel and other bio-fuels are a long term solution that will help to quench India'^s growing energy demand, smartly. 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 (CH4) 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 [2]. 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.

2. Literature Review

Jenbacher Werke AG et al. (1985) [3] Introduced a total energy plant which was able to burn lean gas to produce electricity and heat. They were able to control the air fuel ratio to put more fuel into the cylinder but they needed to modify the cylinder head for bigger inlet valve. A.G.

Wunsche did not define the gas composition but they experienced lower methane number for the gas they used to fuel the engine. Then to prevent knocking they used knock detection sensor and retarded the ignition when it detects knock. The lower power output was still an unsolved issue.

G. A. Karim et al. (1992) [4] They carried out a valuable research on thermodynamic and kinetic characteristics of methane-air combustion in presence of carbon dioxide. G. A. Karim continued to publish more papers regarding the biogas combustion phenomenon in internal combustion engines.

Shalini Singh et al. (2000) [5] Studied the increased biogas production using microbial stimulants. They studied the effect of microbial stimulant aquasan and teresan on biogas yield from cattle dung and combined residue of cattle dung and kitchen waste respectively. The result shows that dual addition of aquasan to cattle dung on day 1 and day 15 increased the gas production by 55% over unamended cattle dung and addition of teresan to cattle dung : kitchen waste (1:1) mixed residue 15% increased gas production.

Kumar et al., (2004) [6] Investigated the reactivity of methane. They concluded that it has more than 20 times the global warming potential of carbon dioxide and that the concentration of it in the atmosphere is increasing with one to two per cent per year. The article continues by highlighting that about 3 to 19% of anthropogenic sources of methane originate from landfills.

Thomsen et al. (2004) [7] found that increasing oxygen pressure during wet oxidation on the digested biowaste increased the total amount of methane yield. Specifically, the yield which is normally 50 to 60% increased by 35 to 40% demonstrating the increased ability to retrieve methane to produce economic benefits.

Carrasco et al. (2004) [8] studied the feasibility for dairy cow waste to be used in anaerobic digestive systems. Because the animal's wastes are more reactive than other cow wastes, the study suggests dairy cow wastes should be chosen over other animal wastes.

3. Description of Experimental Set up

The experimental setup has air-box, fuel tank, calorimeter, modified convergent-divergent nozzle etc. The loading arrangement is also provided in the experimental setup through brake dynamometer. The engine used for the present investigation is a single cylinder, four strokes, water cooled diesel engine which is coupled to the brake dynamometer. It is provided with a board on which the display units and other measuring instruments like rotameter, U-tube differential manometer, and burette setup are given. Diesel is filled in the diesel tank which is placed in above of the panel board. A burette is also placed in the panel board which is used to measure fuel consumption. When engine is start valve of the fuel tank is closed and open valve of the burette. This burette one side is open to fill Biodiesel in different proportion and another side is fitted in the valve. Biogas is supplied to the engine at air supply line, through convergent-divergent nozzle. Biogas consumption is calculated by measuring weight of biogas by weight measuring device. The fuel flow rates are measure by noting time taken for 1 min.

Figure 4: Image of Experimental setup of diesel engine (at UIT RGPV)

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Modified Experimental Setup

The dual fuel engine is basically a modified CI engine. Duel fuel technology mainly consists of two fuels. One which is gaseous fuel, on which the engine runs primarily, is called as primary fuel and the other fuel which is used to initiate the ignition is the pilot fuel. In this case, a mixture of air and biogas is sucked into the engine, compressed and then ignited by a spray of fuel with a low self-ignition temperature such as diesel, vegetable oil or bio-diesel, which is called a pilot fuel. Biogas directly cannot be used to run a CI engine on account of its high self-ignition temperature. Though, it can be consumed in a CI engine with the dual fuel approach. Dual fuel operation always needs a small amount of pilot fuel for ignition to operate diesel engines with biogas and biodiesel, can be suitably converted to a dual fuel engine, which is the most efficient and practical method. Since biogas consists of a high octane number, it can be utilized in a high compression ratio engine to maximize its conversion efficiency. The supplementary components required for biodiesel-biogas duel fuel operation are: Biogas storage device or the Biogas digester, Biogas inlet pipe, hot wire anemometer, Biogas mixing device, four gas analyzer for emission analysis.

This experimental study is for the performance analysis of the biofuels like Biodiesel on mono fuel mode and the Biodiesel-Biogas on the dual fuel mode on different load conditions and at constant speed 1500 rpm. The experimental setup used for this study was based on a vertical, 4-stroke, single cylinder, constant speed, direct injection, compression ignition and water cooled engine. It has a bore of 80 mm, a stroke length of 110 mm, a displacement volume of 553 $cm^3$and a compression ratio of 16.5:1. The rated maximum power was 3.78kW at 1500 rpm. The engine was coupled with a brake dynamometer to apply load. The setup has detached air box, fuel tank, hot wire anemometer, fuel measuring unit, temperature measuring unit etc. The fuel tank is positioned in the panel board which injected the fuel in the engine. The burette was also positioned in the panel board which is used to measure the fuel in the engine. Biogas is admitted to the engine via fuel pipeline, through biogas mixing device. We had attached a hot wire anemometer in the biogas pipeline to measure the velocity of the biogas. This velocity is used in the calculation of mass flow rate of biogas. The schematic block diagram of experimental setup and instruments used for measuring the performance parameters and emission are shown in figure 5. The main aim of this experiment is to investigate the effect on performance of modified diesel engine to run on duel fuel mode with the usage of palm oil biodiesel and biogas. Performance investigation of duel fuel technology on diesel engine was evaluated at different load condition and at constant speed. The test is conceded out on engine by using biogas as a fuel with few additional components and modification, which is required for better performance in compression of the experiment engine. The engine specifications are given in Table no. 2 and block diagram of the experimental setup is shown in figure 5.

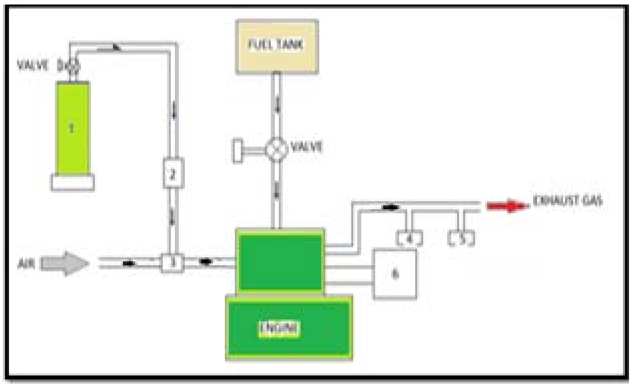

Figure 5: Schematic diagram of the experimental set up

1) Biogas container,
2) Biogas flow meter,
3) Air-Biogas mixing device,
4) Calorimeter,
5) Exhaust gas analyzer,
6) Dynamometer

Table 2: Engine specifications

Parameter	*Details*
Engine	Vertical engine, Kirloskar
Engine Nature	4 stroke single cylinder direct injection CI engine
Type	Water cooled
Brake power	3.7KW
Number of cylinders	1
Bore	80mm
Stroke	110mm
Rated speed	1500rpm (constant)
Combustion	Compression Ignition
Air flow measurement	Air box
Torque measurement	Brake dynamometer
Radius of dynamometer flywheel	0.30 m

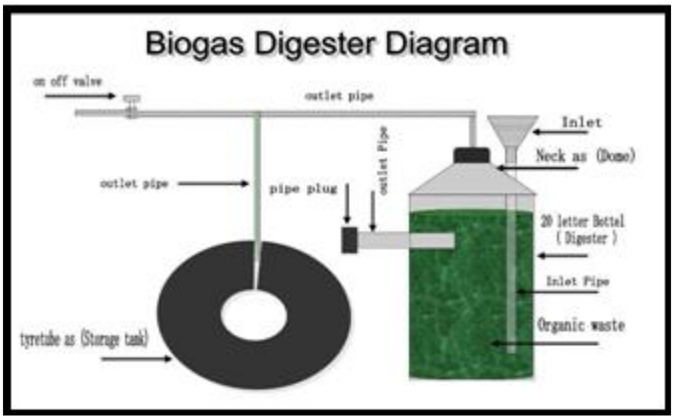

Figure 6: Photographic image of biogas digester at UIT-RGPV

Biogas mixer It is a device which is used for proper mixing of air and biogas. Air is allowed to pass through a constriction; in dynamics, a passes through in according with the principle of continuity, while its static pressure must drop as the principle of conservation of mechanical energy.

Figure 7: Biogas mixer device (Tube)

Thus, any gain in kinetic energy a fluid may increase due to its increased velocity through a constriction is balanced by a drop in pressure. At constriction, the velocity of air is very high hence; biogas is introduced in this narrow pass for proper mixing (figure 8 & 9)

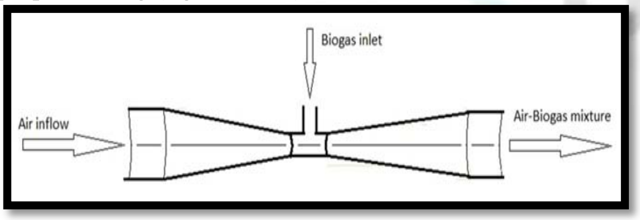

Figure 8: Biogas mixer

Figure 9: Image of Biogas Mixture

Exhaust gas analysis:

Substances which are emitted to the atmosphere from any opening of the exhaust port of the engine are termed as exhaust emissions. If combustion is complete and the mixture is the products of combustion would consist of carbon dioxide (CO2) and water vapour only. However, there is no complete combustion of fuel and hence the exhaust gas consists of variety of components, the most important of them are carbon monoxide (CO), unburned hydrocarbons (UBHC) and oxides of nitrogen (NOx). Some oxygen and other inert gases would also be present in the exhaust gas. Over the decade numerous devices have been developed for measuring these various exhaust components. A brief discussion of some of the more commonly used instruments.

Figure10: Indus 5 Gas Analyzer Model: PEA 205N

BIOGAS

Biogas is produced by bacteria through the bio-degradation of organic material under anaerobic conditions. Natural generation of biogas is an important part of bio-geochemical carbon cycle. It can be used both in rural and urban areas.

Table 1: Composition of Biogas

Component	Concentration (by volume)
Methane (CH_4)	55- 60%
Carbon dioxide (CO_2)	35- 40%
Water (H_2O)	2-7 %
Hydrogen Sulphide ($H_2 S$)	20-20,000ppm (2%)
Ammonia (NH_3)	0-0.0 5%
Nitrogen (N)	0-2 %
Oxygen (O_2)	0-2 %
Hydrogen (H)	0-1 %

Biogas digester

Biogas digester has captured many imaginations because they can turn organic wastes from our farms, factories and cities into a valuable source of renewable energy. In addition, the potential of this technology to reduce odours and other environmental concerns of animal feedlots has resulted in much recent interest from farmers. On-farm uses are not, however, the only digester options. Indeed, other industries have been reaping the benefits of digestion for years, particularly for wastewater treatment. While digesters can be a useful source of energy, they probably will never supply a significant portion of our state's energy needs – it's estimated that farm digesters could at most provide about one and a half percent of Minnesota's energy needs.

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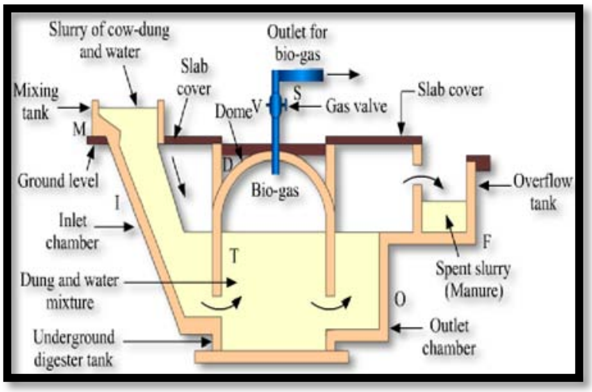


Figure 1: Floating gas-holder type bio-gas plant [9]

Components of a typical biogas plant

Digester: A digester in which the slurry (dung mixed with water) is fermented, an inlet tank for mixing the feed and letting it into the digester, gas holder/dome in which the generated gas is collected, outlet tank to remove the spent slurry, distribution pipeline(s) to transport the gas into the kitchen, and a manure pit, where the spent slurry is stored.

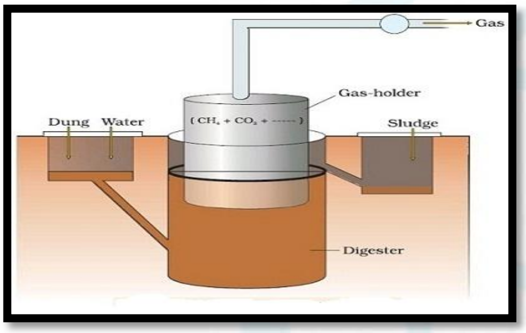


Figure 2: Digester (dung mixed with water)

Process stages: The four important stages of anaerobic digestion involve hydrolysis, acid genesis and methanogensis. The overall generation process can be described by the chemical reaction, where organic material such as glucose is biochemically digested into carbon dioxide (CO2) and methane (CH4) by the anaerobic microorganisms.

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

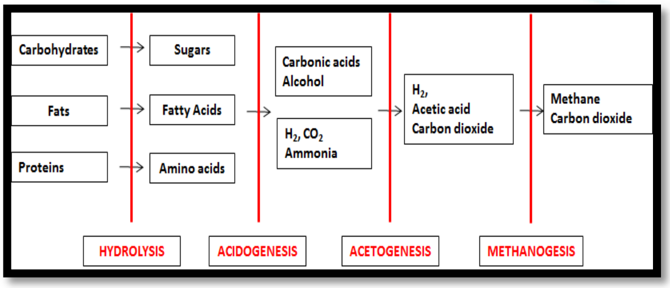


Figure 3: Process stages Flow Chart

a) **Hydrolysis**: Generally, most the cases, biomass is made up of large organic polymers. For the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These ingredient parts, or monomers, such as sugars, are readily available to other bacteria. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis. Therefore, hydrolysis of these high-molecular-weight polymeric components is the necessary first step in anaerobic digestion. Through hydrolysis the complex organic molecules are broken down into simple sugars, amino acids, and fatty acids. Acetate and hydrogen produced in the first stages can be used directly by methanogens. Other molecules, such as volatile fatty acids (VFAs) with a chain length greater than that of acetate must first be catabolized into compounds that can be directly used by methanogens.

b) **Acidogenesis**: The biological process of acidogenesis results in further breakdown of the remaining components by acidogenic bacteria. Here, VFAs are created, along with ammonia carbon dioxide, and hydrogen sulfide, as well as other byproducts. The process of acidogenesis similar to the way milk sours.

c) **Acetogenesis:** The third stage of anaerobic digestion is acetogenesis. Here, simple molecules created through the acidogenesis phase are further digested by acetogenesis to produce largely acetic acid, as well as carbon dioxide and hydrogen.

d) **Methanogenesis** The terminal stage of anaerobic digestion is the biological process of methanogenesis. Here, methanogens use the intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water. These components make up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low PH and occurs between pH 6.5 and pH 8. The remaining, indigestible material the microbes cannot use and any dead bacterial remains constitute the dig estate.

Biogas Generation

Biogas is produced by extracting chemical energy from organic materials in a sealed container called anaerobic digester by the biological process in the absence of oxygen. It is a naturally occurring microbiological process that converts the organic matter to methane and carbon dioxide. The anaerobic biological conversion of organic matter occurs in three steps. The first step involves hydrolysis where transformation of insoluble organic material and higher molecular mass compounds such as lipids, polysaccharides, proteins, fats, nucleic acids, etc. into soluble organic materials, i.e. to compounds suitable for the use as source of energy and cell carbon such as monosaccharide, amino acids and other simple organic compounds [10]. Next step involves acid formation where group of microorganisms ferments the break-down products to acetic acid, hydrogen, carbon dioxide and other lower weight simple volatile organic acids like prop ionic acid and butyric acid which are in turn converted to acetic acid. Third step where the anaerobic bacteria called as methane formers converts the organic acids formed in second stage into biogas having its main constituents as methane and carbon dioxide with other small traces of H2S, H2 and N2.

Biogas purification

Biogas can be use more efficiently in diesel engine after its purification. Now biogas can be used directly to generate power, but present in the large volume of carbon dioxide (CO2) reduces the heating value of the gas, increasing compression and transportation costs and limiting economic feasibility to uses that occur at the point of production. Purification is wider variety of uses, either for electricity and heat, or for vehicle fuels. For use as a fuel, purification to remove carbon dioxide (CO2) and hydrogen sulfide (H2S) is required, because present H2S corrodes vital mechanical components within IC engine sets and vehicle performance if it is not removed. Although the exhaust of engine in also harmful for the environment and human health. Biogas emits fewer amounts of nitrogen oxide, hydrocarbon and carbon monoxide than gasoline or diesel, and engines fueled by purified biogas are quieter. Refueling with biogas presents fewer environmental and health risks than refueling with gasoline or diesel, because it must required a small unit located at an owner's home or industry, minimizing the potential impacts if leaks or spills occur. Feasible biogas purification technologies exist for large-scale biowaste and sewage digesters, and the technologies for upgrading biogas, compressing, storing and dispensing biomethane are well developed. The following techniques are used for purification:

1) Biogas Purification Technologies [11]
a) Scrubbing
b) Chemical Absorption
c) Pressure Swing Adsorption
d) Membrane Purification
e) Cryogenic Separation
f) Biological Processes

2) H_2S Removal Methods:
a) Air/Oxygen Dosing to Digester Biogas
b) Iron Chloride Dosing to Digester Slurry
c) Iron Sponge
d) Iron Oxide Pellets
e) Activated Carbon
f) Water Scrubbing
g) NaOH Scrubbing
h) Biological Removal on a Filter Bed
i) Air Stripping & Recovery

Biogas utilization
Today biogas applications are wider in the various fields because of its than diesel engines. availability and free of air pollution. Biogas is not limited in the only generates energy but also plays important role in waste management, environment cleaning and gives guarantee of continuous fuel supply in future. Conventionally biogas is consumed for cooking in India but with increasing faith in renewable energies. The biogas application area is widening.

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

4. Results and Discussion

In this present work, the biogas is used in compression ignition engine in different proportion where diesel is used as a main fuel, engine is operates in dual fuel mode. The performance and emission characteristics of with and without biogas are compared with diesel operation.

Performance Parameter

Brake Specific Fuel Consumption
In figure 11 shows the variation of BSFC with brake power for neat diesel. This graph shows BSFC is decreasing to increasing brake power because of the chemical energy content of fuel is converted into useful work. At high engine speed the fuel combustion is improved due to better mixing of fuel and air. While at high engine load the combustion is improved due to higher in-cylinder temperature after successive working of engine at this load that is would improve fuel atomization and evaporation processes and partially improve fuel air mixing process.

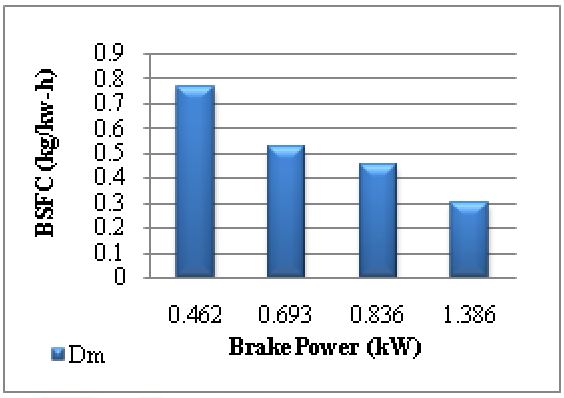
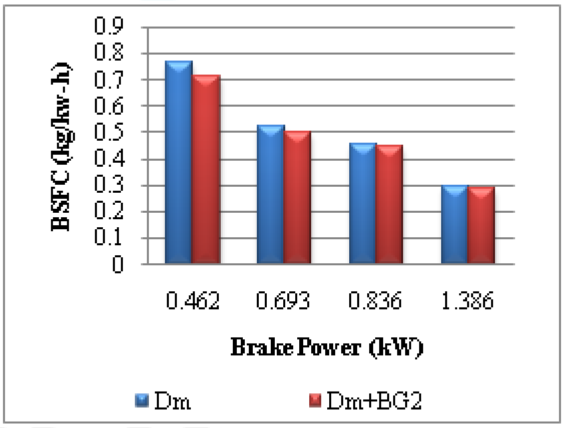
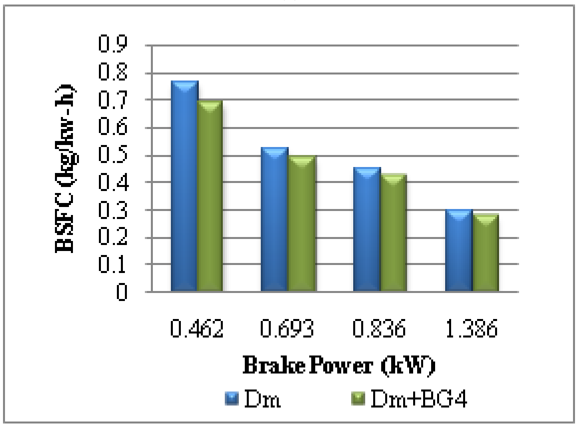


Figure 11: Variation of BSFC vs. brake power to diesel



(I)



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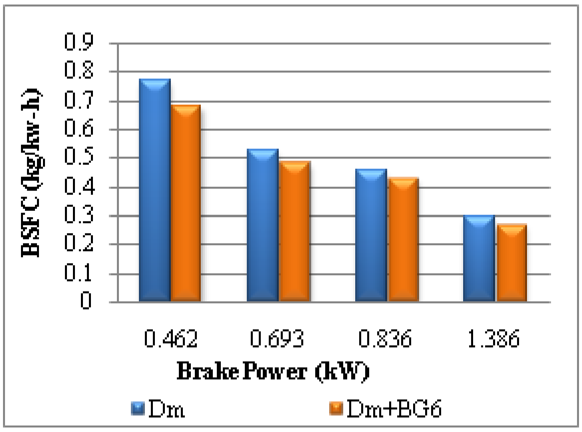

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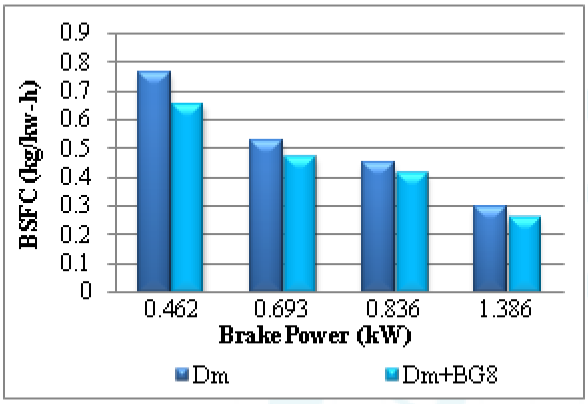


(IV)

Figure 12: (I, II, III, IV)Show Variation of BSFC vs. brake power to diesel and biogas (2mg+4mg+6mg+8mg)

Figure 12 shows variation of BSFC with brake power mono fuel mode to with biogas in dual fuel mode. When we compared to diesel of its increasing biogas mass flow rate, BSFC is decreasing continuously because biogas contains some lower calorific value.

Brake Thermal Efficiency (BTE)

Figure 13, shows variation of brake thermal efficiency with brake power for neat diesel and biodiesel in mono fuel mode. The brake thermal efficiency indicates the ability of the combustion system to accept the investigational fuel and provide comparable means of evaluating how efficiently energy in the fuel can be converted into mechanical productivity. This graph indicates increase the brake thermal efficiency on increasing brake power.

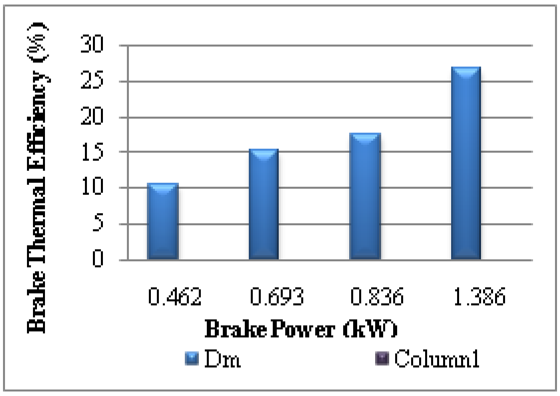
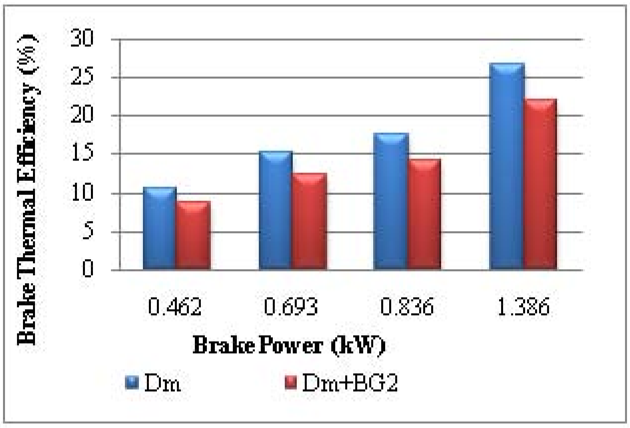


Figure 13: shows variation of brake thermal efficiency



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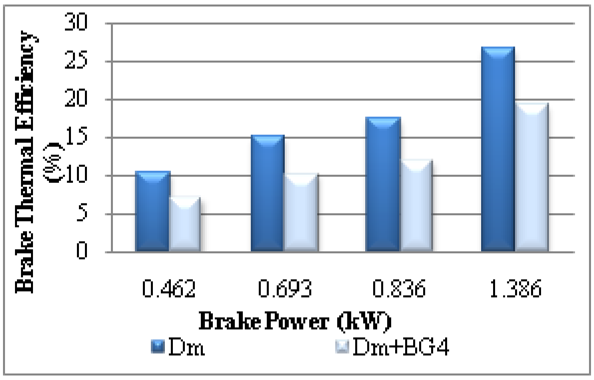

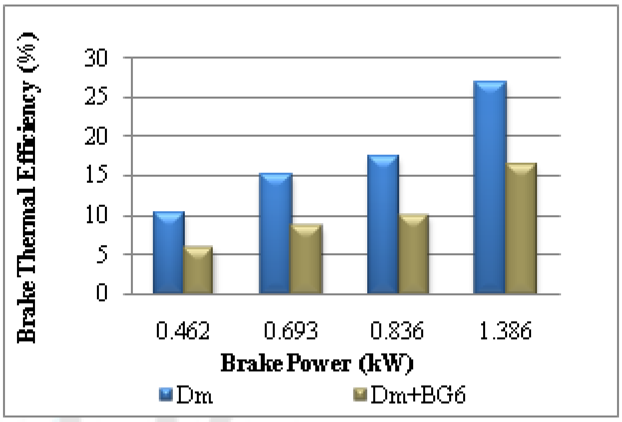

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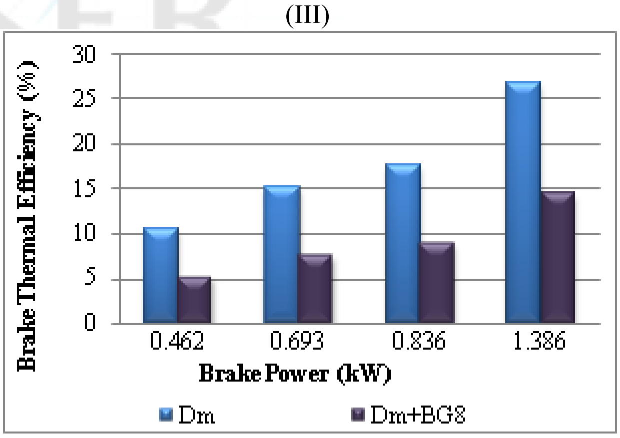

(IV)

Figure 14: (I, II, III, IV) Variation of BTE vs. Brake power of diesel and biogas (2mg+4mg+6mg+8mg)

The Figure 14 shows the variation of Brake thermal efficiency with Brake power for neat diesel in mono fuel mode and its increasing mass flow rate of biogas. These charts indicate when increasing mass flow rate of biogas brake thermal efficiency is decreasing continuously because carbon dioxide (CO_2) present in biogas. To increasing the mass flow rate of biogas cool the engine because of present in CO_2.

Emission Parameters

Carbon monoxide (CO) emission

Figure 15 shows variation of CO emission with Brake power of diesel mono fuel mode. This chart indicates when brake power increases to reduce the CO emission.

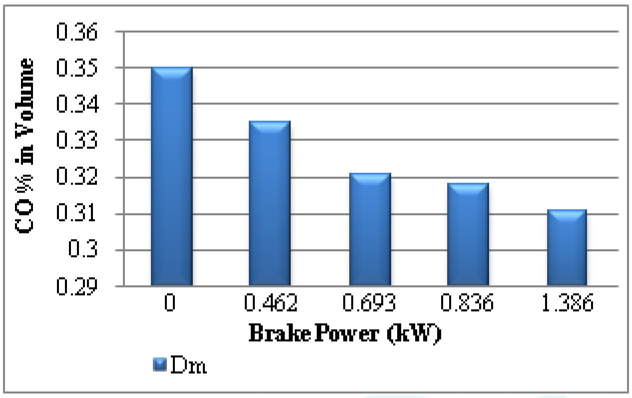

Figure 15: Variation of CO emission vs. Brake power of diesel

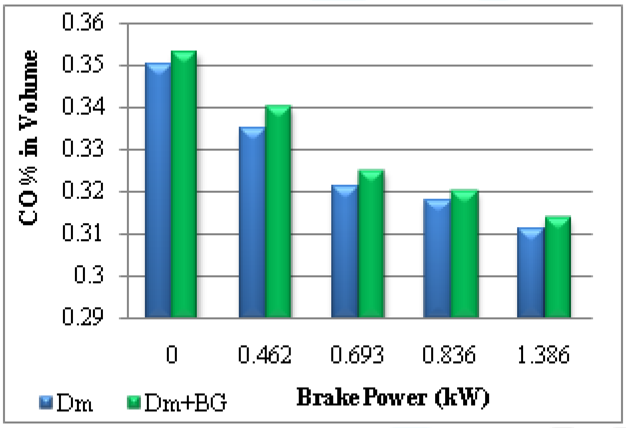

Figure 16: Variation of CO emission vs. Brake power of diesel and biogas

Figure 16: shows the variation of the CO emission with Brake power of diesel mono fuel mode and its combine with biogas in dual fuel mode. These charts shows when engine is run single fuel mode CO emission are less as compared to when engine run in pilot fuel with biogas in dual fuel mode. In engine when supply the biogas, these contains large amount of CO2, so incomplete combustion is take place in combustion chamber. Now this incomplete combustion CO emission is more than single fuel mode.

Hydrocarbon (HC) emission

Figure 17: shows the variation of HC emission with Brake power of diesel mono fuel mode. This chart indicated HC emission of diesel is decreasing to increasing brake power because diesel higher cetane no., which leads to better combustion in combustion chamber.

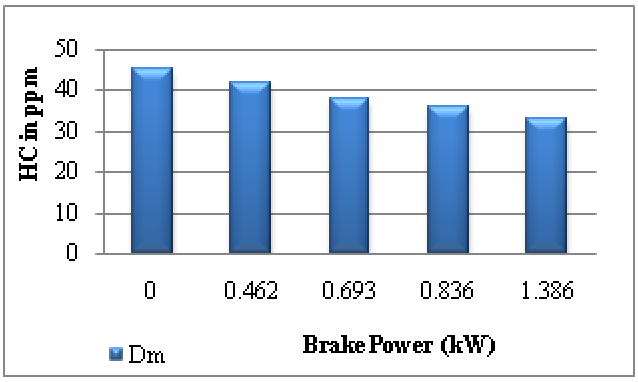

Figure 17: Variation of HC emission vs. Brake power of diesel

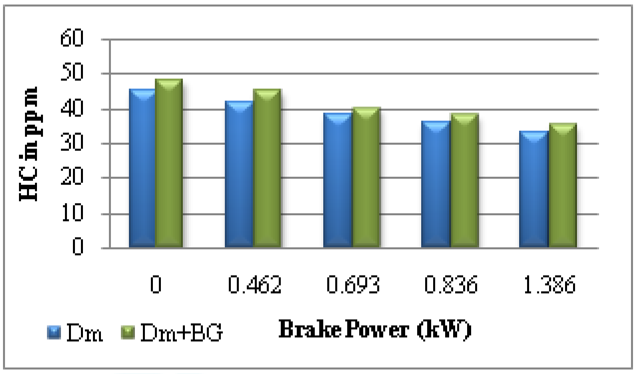

Figure 18: Variation of HC emission vs. Brake power of diesel and biogas

Figure 18, shows the variation of the HC emission with Brake power of diesel mono fuel mode and its combine with biogas in dual fuel mode. These charts indicate when engine runs mono fuel mode emits less HC in compression of when engine runs to induction biogas in dual fuel mode in different brake power. When induction of biogas into the engine, CO_2 content in combustion chamber is increases at the expense of fresh air which is reduces the air-fuel ratio and combustion temperature.

Carbon dioxide (CO_2) emission

Figure 19, shows the variation of CO_2 emission with Brake power of diesel mono fuel mode. This chart indicated that when increasing brake power, CO_2 emission decreases continuously due to incomplete combustion of fuel at high brake power. At high brake power require more amount of fuel as compare to low brake power, availability of air is not enough to perform complete combustion at high brake power.

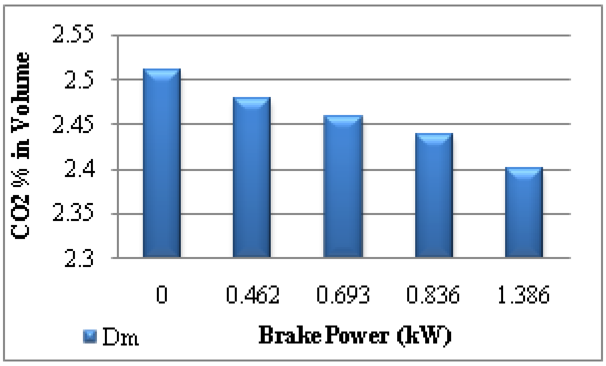

Figure 19: Variation of CO_2 emission vs. Brake power of diesel

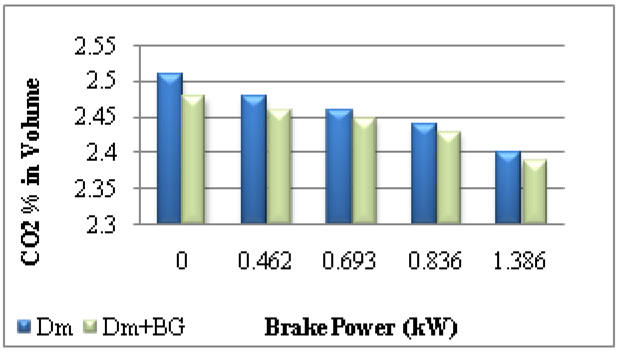

Figure 20: Variation of CO_2 emission vs. Brake power of diesel and biogas

Figure 20, shows the variation of the CO_2 emission with Brake power of diesel mono fuel mode and its combine with biogas in dual fuel mode. These charts indicate when engine runs mono fuel mode emits more CO_2 in compression of when engine runs to induction biogas in dual fuel mode in different brake power. When induction of biogas into the engine for combustion, the combustion chamber less availability of oxygen and low combustion temperature, Due to deficiency of oxygen incomplete combustion take place and emits less CO_2.

5. Conclusion

The performance and emission characteristic of a single cylinder, four stoke, water cooled, diesel engine having a power output of 3.7 kW at a constant speed of 1500 rpm, fuelled diesel with and without biogas mono and dual fuel mode have been analyzed and compared with diesel. The following are conclusions:

1) The energy share of diesel is decreases continuously on increases mass flow rate of biogas because biogas contains low calorific value.
2) The BSFC of diesel is decreases continuously on increases mass flow rate of biogas is less at high brake power as compare to diesel at mono fuel mode.
3) Brake thermal efficiency of diesel is decreases continuously on increases mass flow rate of biogas is less at high brake power as compare to diesel at mono fuel mode.
4) The emission of CO increases in diesel with biogas in dual fuel mode as compare to diesel in mono fuel mode.
5) The emission of HC increases in diesel with biogas in dual fuel mode as compare to diesel in mono fuel mode.
6) The CO_2 emission decreases in diesel with biogas in dual fuel mode as compare to diesel in mono fuel mode.

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