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Performance study of four stroke S.I. engine using upgraded biogas fuel

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Abstract: In resent year, increased environmental awareness and energy shortages have encouraged researchers to investigate the possibility of using alternate fuels. The purpose of finding the alternate sources is to minimize the consumption of conventional fossil fuels and in turn to reduce the degradation of environmental quality to a great extent. The use of bio-based fuels like biogas produced from biomass and bio-wastes is a valuable energy source which is sustainable that can be manufactured from locally available waste streams thereby solving the local waste problem. Local wastes (organic wastes) contain enough energy to contribute significantly to energy supply especially the rural regions of developing countries. Biogas is a clean and environment friendly fuel produced from anaerobic digestion of agro, animal or human wastes. The biogas has about 60 % methane and 40 % carbon dioxide with small traces of H_2S. The use of H_2S leads to formation of SO_2 which combines with the water vapor to form acids and hence corrode the metals. Thus, raw biogas as such cannot be used for powering vehicular I.C engine. In the present work, an attempt has been made to upgrade the quality of raw biogas by removing CO_2 and H_2S, thus enriching its methane content up to the natural gas level and to study the performance of four stroke S.I engine aspirating upgraded biogas as primary fuel and its emission characteristics.

Keywords: upgraded biogas; low grade water scrubber; S.I engine; biogas carburetor; engine emissions.

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1 Introduction: Raw Biogas is suitable fuel for heating and cooking purposes but when it is to be used for powering vehicles, the presence of CO_2 lowers the engine power output. Moreover, raw biogas does contain H_2S which leads to formation of SO_2 and acidic vapor that may damage the engine. Thus it is essential to remove most of the CO_2 and H_2S from raw biogas obtained from anaerobic digestion of organic wastes to prepare it for use as fuel for automotive vehicles.

Natural gas has 75-98 % methane with small percentage of ethane, butane and propane while raw biogas has about 50-60 % methane, 30-40 % CO_2, 5-10 % H_2, 0.5-0.7 % N_2, with trace of H_2S. Its energy density is about 23 MJ/m^3. It is thus possible to improve the quality of biogas (upgrading) by enriching its methane content up to the natural gas level. After methane enrichment and compression in the cylinder, it is just like CNG which is a clean and efficient fuel.

Gas composition has a great impact on the performance and emission characteristics of the engine. Flame speed, ignition delay and knock characteristics are affected by fuel gas composition which affect the spark timing and air/fuel ratio. The physical and chemical properties of biogas affect the choice of technology used for combustion and knowledge of these properties is essential to modify the existing S.I engine system to operate on upgraded biogas.

This study incorporates the development of less expensive purification units using local resources for up- gradation of raw biogas obtained from anaerobic digester in to upgraded biogas with 75-85 % methane content.

The upgraded biogas obtained from purification unit is tested on four stroke S.I engine to study its performance and emission characteristics. A gas carburetor has also been designed and developed for engine testing. The tests prove stable operation during starting, idling and no load operation and establish the success of conversion of conventional gasoline engine to operate on upgraded biogas manufactured. The results obtained from the experiments conducted under full throttle open condition show substantial reduction in CO, NOx, HC and CO_2 with improved engine performance compared to raw biogas **[1 - 5]**.

1.1 Fuel properties of raw biogas: Composition of raw biogas is

CH_4: 50 %
CO_2: 43 %
H_2S: 3.94 %
Moisture: 2.4 %
Calorific value: 23000 kJ/m^3
Stoichiometric air- methane ratio (by volume): 10:1
Explosive limits (by volume): 5-10
Ignition temperature: 650^0c
Octane rating: 110

1.2 Purification of Biogas:

Biogas is suitable as a fuel for most purposes without processing. But if it is to be used for powering vehicles, the presence of CO_2 is not desirable for a number of reasons. First it lowers the power output from the engine and the presence of H_2S initiate formation of SO_2 and acidic vapor that occupies more volume in the storage cylinder. Thus, CO_2 and H_2S must be removed from raw biogas to upgrade it to be useful for S.I engine.

The simplest and cheapest method of removing CO_2 is by washing the gas with water under pressure. This can be achieved by the method of scrubbing which yields biogas with methane content close to 75-95% which is pure enough for vehicular use. The scrubber also removes effectively corrosive sulphides. Thus scrubbing of raw biogas is essential step for purification.

A low cost water scrubber has been designed and developed from resources available locally like plastics barrel of 1 m high and 0.75 m in diameter. The water at a pressure 1.5 kg/cm^2 is used as absorbent. This pressurized water is connected at top of the plastic barrel with fine water spray fogger which sprays continuously pressurized water from the top. The raw biogas is fed directly from biogas digester with a pressure of 1.5 kgf/cm^2 into the plastic barrel from the bottom. The absorption process is thus counter current type. This dissolves CO_2 as well as H_2S in water and is collected at the bottom of the barrel tower while the purified gas is collected from the top of the barrel. To remove the moisture from purified biogas, it is passed through a Column of Silica gel bed and is collected for use in I.C engine.

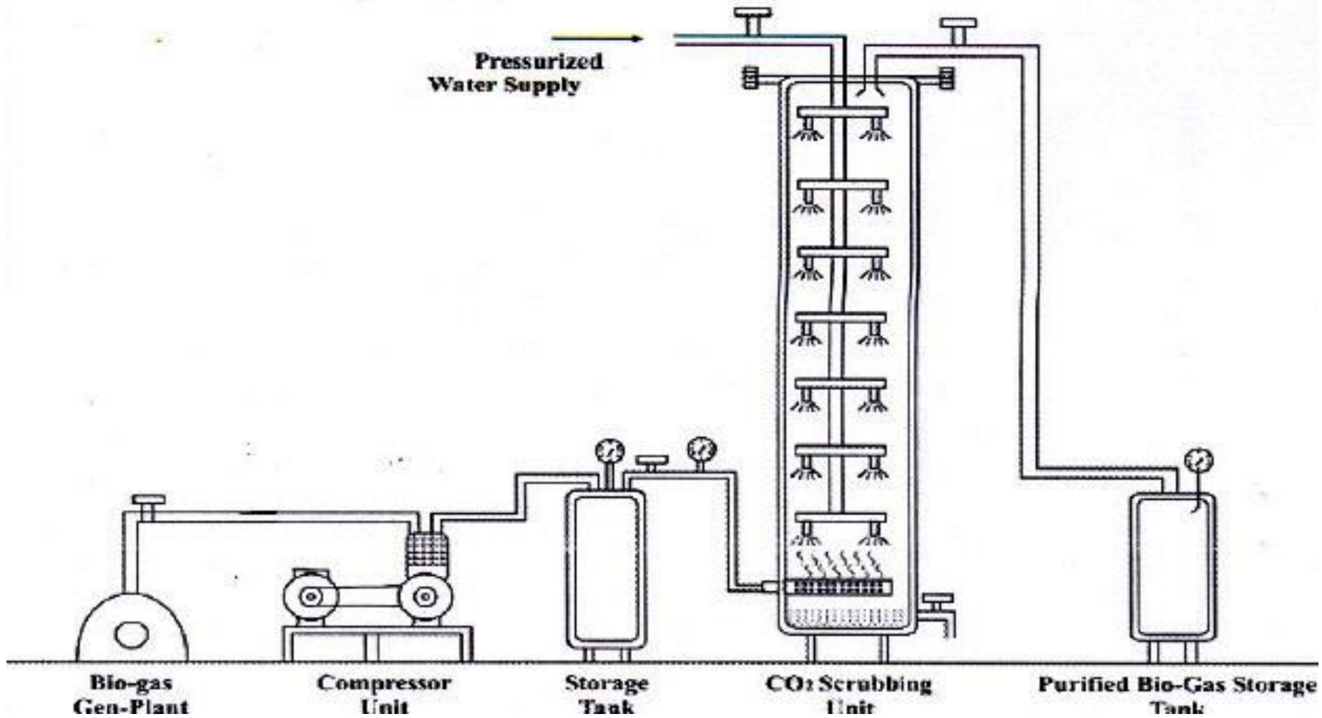

Figure 1: Biogas purification unit.

1.3 Fuel properties of purified biogas: Composition of purified biogas is

CH_4: 71.8 %
CO_2: 19.8 %
H_2S: 1.04 %
Calorific value: 33000 kJ/m^3
Stoichiometric air- methane ratio: 10:1
Ignition temperature: 650^0c
Octane rating: 130

1.4 Biogas Purification result by water scrubbing method:

Biogas contents	**Raw biogas (%)**	**Purified biogas (%)**	
		P = 1.5 bar	**P = 3 bar**
CH_4	50	71.8	73
CO_2	43	19.8	17.81
H_2S	3.94	1.04	0.88
Moisture	2.40	7.76	7.30

Result shows increasing trend of biogas methane content after purification with respect to feeding pressure.

1.5 Development of Biogas engine:

The performance study was performed on Hero Honda Splendor motor cycle engine with following Specification:

Power: 5 kW
Total volume: 100 cc
No. of cylinder: 1
Type: S.I engine
Stroke: 4 Stroke
Type of cooling: Air cooled
Compression ratio: 9.2:1
Control: Throttle valve controlled

For adaption of biogas fuel in the given engine the induction system of the engine was modified. Petrol carburetor was replaced with biogas carburetor which was designed, developed and installed in the induction system for feeding of upgraded biogas in to the engine cylinder. The pressure of purified biogas was regulated with the help of pressure regulator closed to atmospheric pressure.

1.6 Design of gas carburetor:

A venturi type biogas mixture was designed and fabricated for a 100cc four stroke S.I engine application. During suction stroke, the engine inhales air through carburetor. The throttle valve controls the amount of air entering the cylinder of the engine. The air gets accelerated at the throat of venturi of the carburetor. The reduction in the cross-section area at venturi increases the air velocity which creates the vaccum at the venturi throat. The biogas is introduced at the throat of the venturi where air and biogas mix and the mixtures enters engine cylinder where it is ignited by the spark plug provided in the cylinder head.

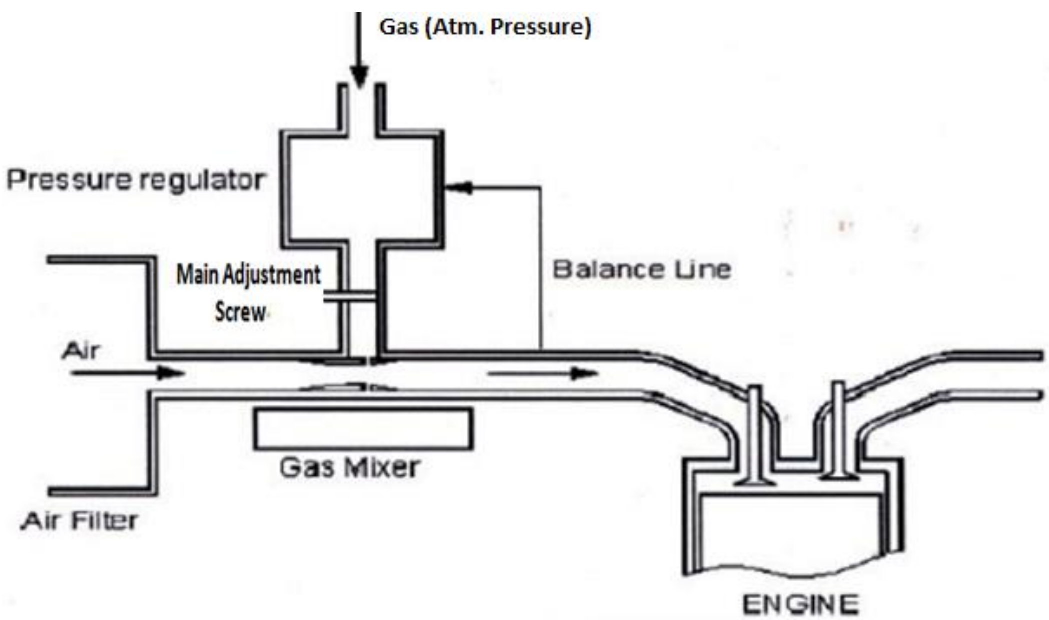

Fig 3: Schematic Diagram of Air, Gas and Mixture Flow

1.7 The following assumptions were made during the design and analysis of biogas carburetor

- Air enters the venturi at ambient conditions
- The biogas was supplied at atm. pressure
- A vacuum of 30 cm of water at venturi throat is enough to induct the required quantity of gaseous fuel
- Compressibility effect of air and the biogas fuel is neglected.

Applying steady flow energy equation to the flow through venturi

$$h_1 + \frac{c_1^2}{2g} + Q = W + h_2 + \frac{c_2^2}{2g}$$

where 1 and 2 refers to the ambient condition and state at venturi throat

As Q = W = 0, also $V_1 = 0$

$$\therefore c_2 = \sqrt{2g(h_1 - h_2)}$$

$$= \sqrt{2g\,c_p(T_1 - T_2)}$$

But $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

$$\therefore C_2 = \sqrt{2g\,c_p T_1\left(\left(1 - \frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right)}$$

For adiabatic process

$$P_1 v_1^{\gamma} = P_2 v_2^{\gamma}$$

Or $v_2 = v\left(\frac{P_1}{P_2}\right)^{\frac{1}{\gamma}}$

For continuity equation

$$m = \frac{A_1 C_1}{v_1} = \frac{A_2 C_2}{v_2}$$

$$\therefore m = \frac{C_d A_2}{v_2}\sqrt{2g\,c_p T_1\left(\left(1 - \frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right)} \quad \text{….. (1.1)}$$

1.8 Specifications of Honda engine:

Total volume of cylinder: 100cc

Compression ratio: 9.1

Clearance volume: 10.99

Swept volume: 89 x 10^{-6} m^3

Rated rpm: 1800

Swept volume per minute: 0.0801 m^3/min

Assuming volumetric efficiency: 0.8

Volume of air inducted: 0.06408 m^3/min

Mass of air inducted (m_a): 0.074 kg/min

For 90% throttle opening, (m_a): 0.066 kg/min

m_f : 0.0066 kg /min.

Assumed C_d: 0.8

Properties of air	**Properties of bio gas**
R= 287 J/Kg-K	R= 518 J/Kg-K
Cp=1005 J/Kg-K	Cp=2165 J/Kg-K
T_1 = 300 K	T_1 = 300 K
P_2 = 0.96 bar	P_2 = 0.96 bar
P_1 = 1.0 bar	P_1 = 1.0 bar
ρ= 1.16 kg/m^3	ρ= 0.6435 kg/m^3
γ= 1.4	γ= 1.314

Substituting the value in Equation 1.1, we get
Diameter of venturi for air (D_a): 16.74 mm
Diameter of biogas jet (D_g): 0.89 mm

This Study aims to modify spark ignition, four strokes two wheeler Honda engine to run on up-graded biogas only and the modification involves an addition of biogas carburetor for mixing of air and biogas and advancement of ignition timing along with provision of gas kit to regulate the gas flow.

The ignition and burning characteristic of upgraded biogas are considerably different from that of gasoline. Biogas has a large delay period and has higher minimum ignition energy requirement compared to gasoline. Thus with the use of upgraded biogas in S.I engine, the combustion duration is relatively longer and requires more advancement of spark timing. The function of the regulator is to provide precise fuel pressure regulation to the mixture. As the load on the engine increases regulator allows higher gas flow rate and vice versa at pressure close to atmosphere.

2. Experimental setup

The experimental facilities used for S.I engine test are shown in figure 4. A four stroke S.I splendor Honda two wheeler research engine along with dynamometer fitted with computer-based display unit and processing system was employed. Supply of biogas was metered with metering device. The system has the facility to measure the exhaust emissions and temperature. Tests were performed at an engine speed ranging from 1600- 6000 rpm.

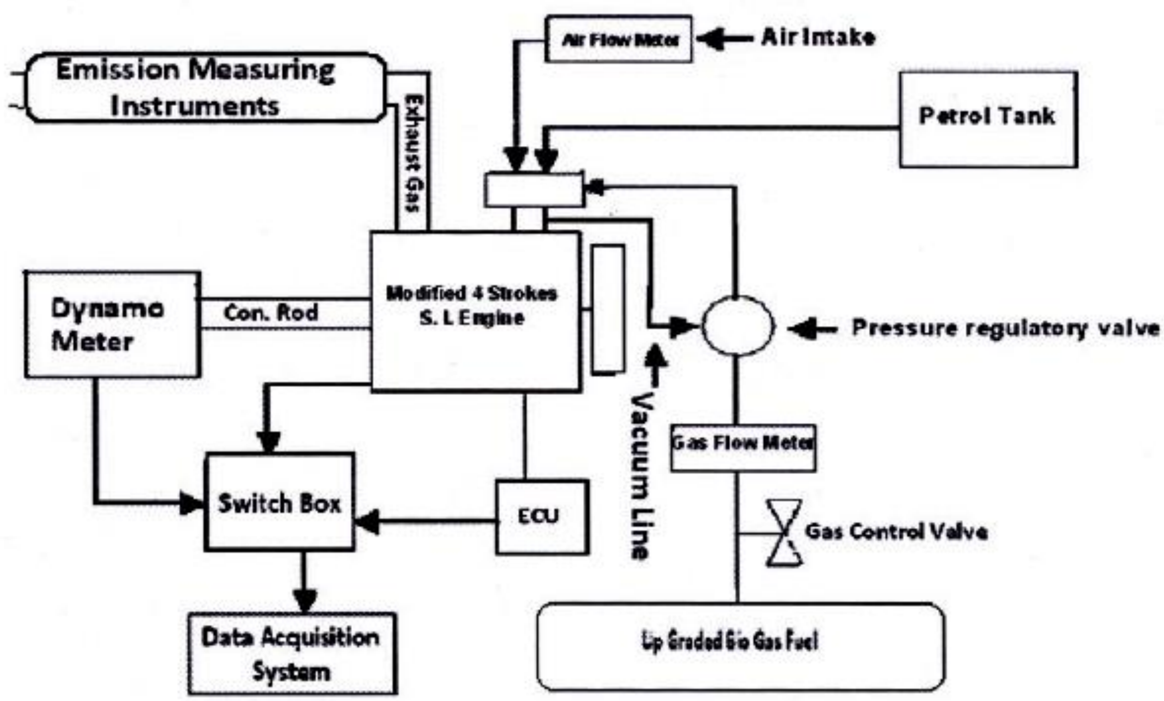

Figure 4: Experimental Set-up of Modified 4 Stroke S. I. Engine.

3. **Performance testing, results and discussions**

The results from the experiments performed on biogas engine are shown in the graph form. For engine performance, engine torque, brake power, brake specific energy consumption and exhaust gas temperature were measured and plotted against varying engine speed from 1600 rpm to 6000 rpm. On the other hand, the graphs of engine emission such as Carbon monoxide (CO), Hydrocarbons (HC), Oxides of nitrogen (NOx) and Carbon dioxide (CO_2) were plotted against the same range of engine speed.

3.1 Engine torque : The engine torque were measured with three different spark advance timing i.e. 35^0, 40^0, and 45^0 for upgraded and raw biogas. 35^0 advanced timing shows better performance without any undue vibration, easy of cold start, less noise and smooth accelerations as shown in figure 5.

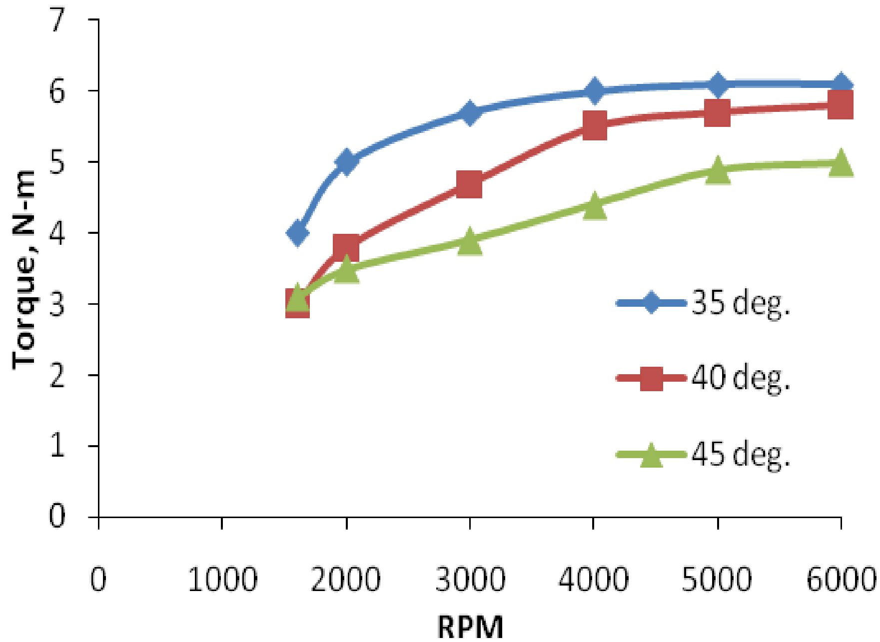

Figure 5: Biogas Fueled Engine Torque v/s Spark Advance.

Engine torque under full throttle condition was also measured for gasoline, raw biogas and upgraded biogas with varying speeds. The graph (figure 6) shows that energy input for raw biogas and upgraded biogas operation is lower than gasoline because of lower calorific value of the raw and upgraded biogas thus the energy released during combustion of raw and upgraded biogas was lower than gasoline operation.

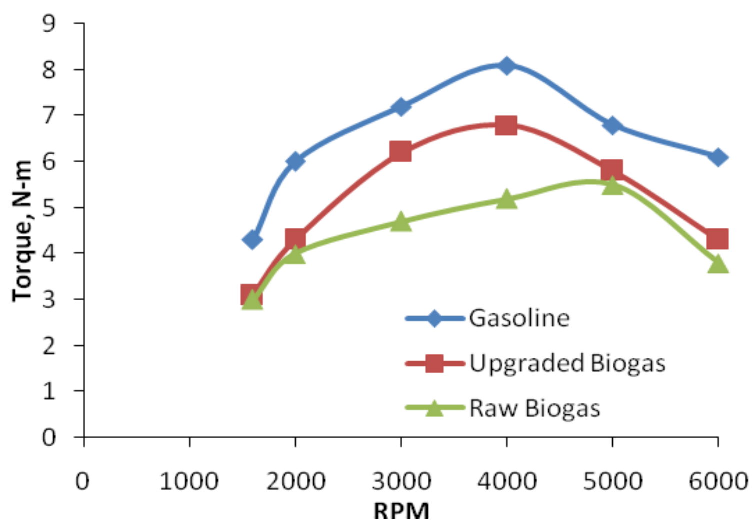

Figure 6: Engine Torque v/s RPM.

3.2 Engine brake power: Engine brake power shows (figure 7) a slight decrease in engine brake power for raw biogas compared to upgraded biogas due to lower calorific value of raw biogas. The brake power for raw biogas and upgraded biogas were found to be 38% and 12% lower than gasoline brake power.

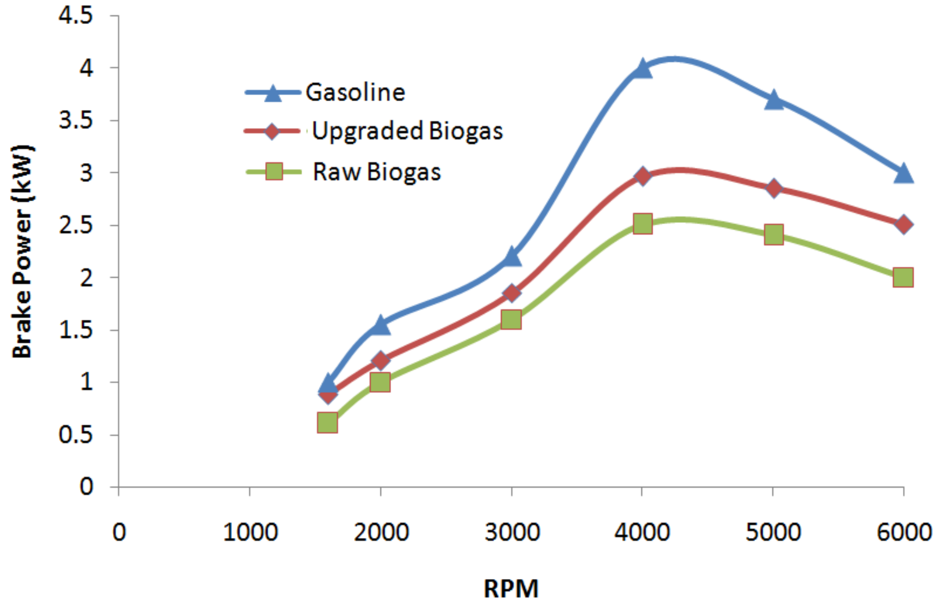

Figure 7: Engine Brake Power v/s RPM.

3.3 Brake Specific fuel consumption: The bsfc for raw biogas and upgraded biogas fuel was found to be lower than gasoline from low to high engine speeds by an average of 19.5% because of less brake power developed by the biogas owing to lower calorific value.

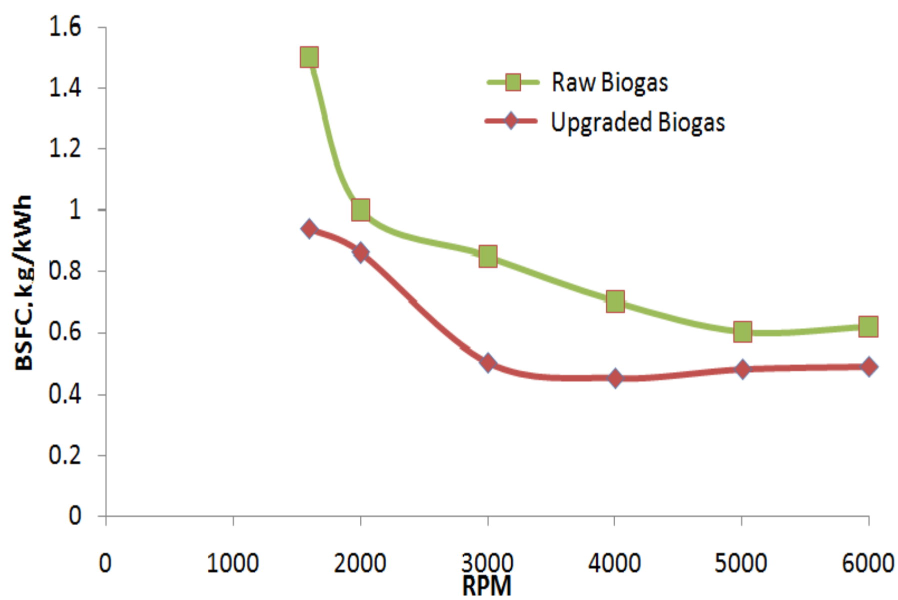

Figure 8: BSFC v/s RPM.

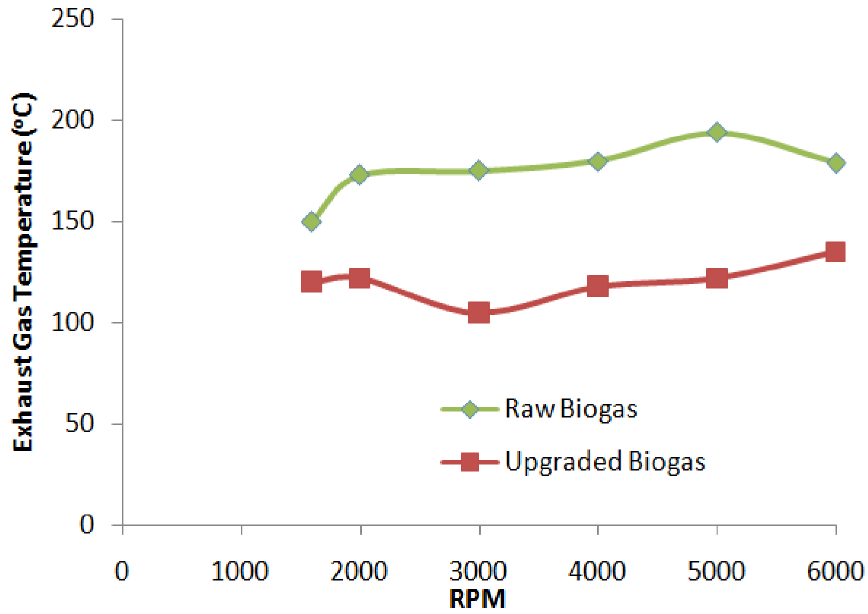

Figure 9: Exhaust Gas Temperature v/s RPM.

3.4 Engine missions:

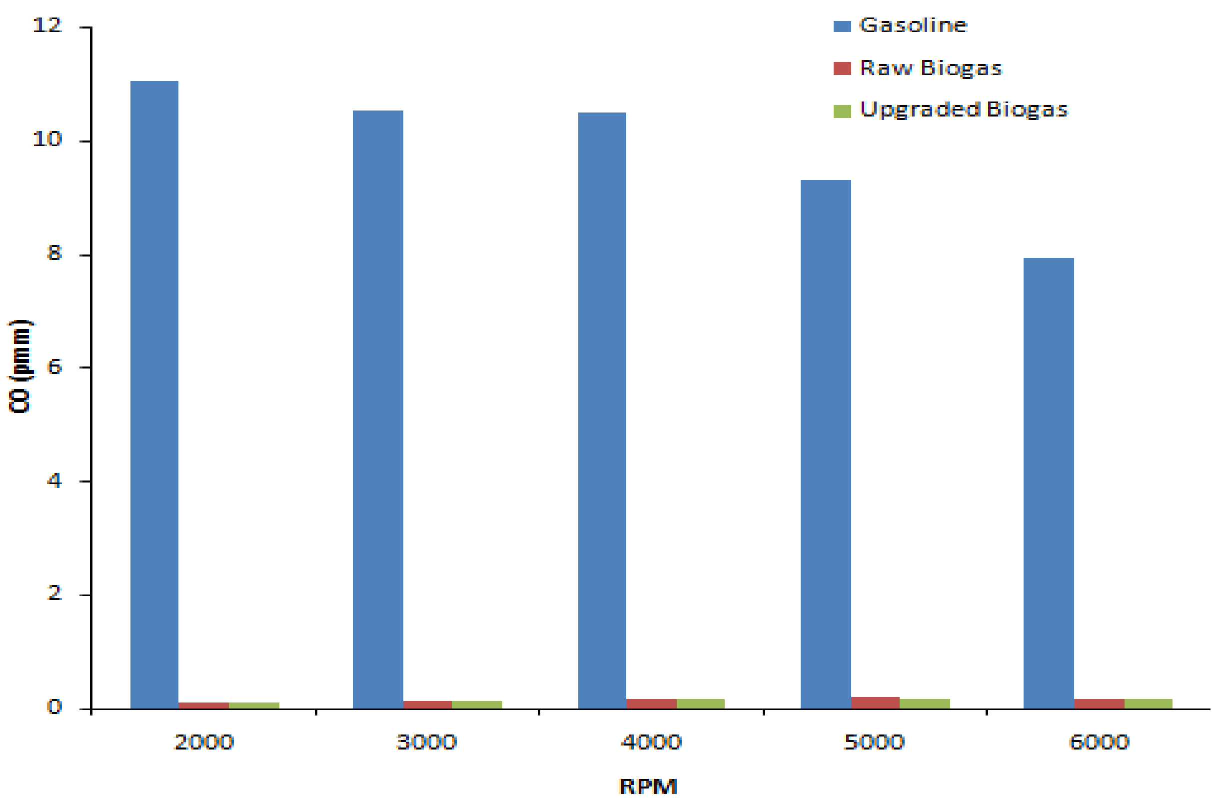

Figure 10: CO Emissions.

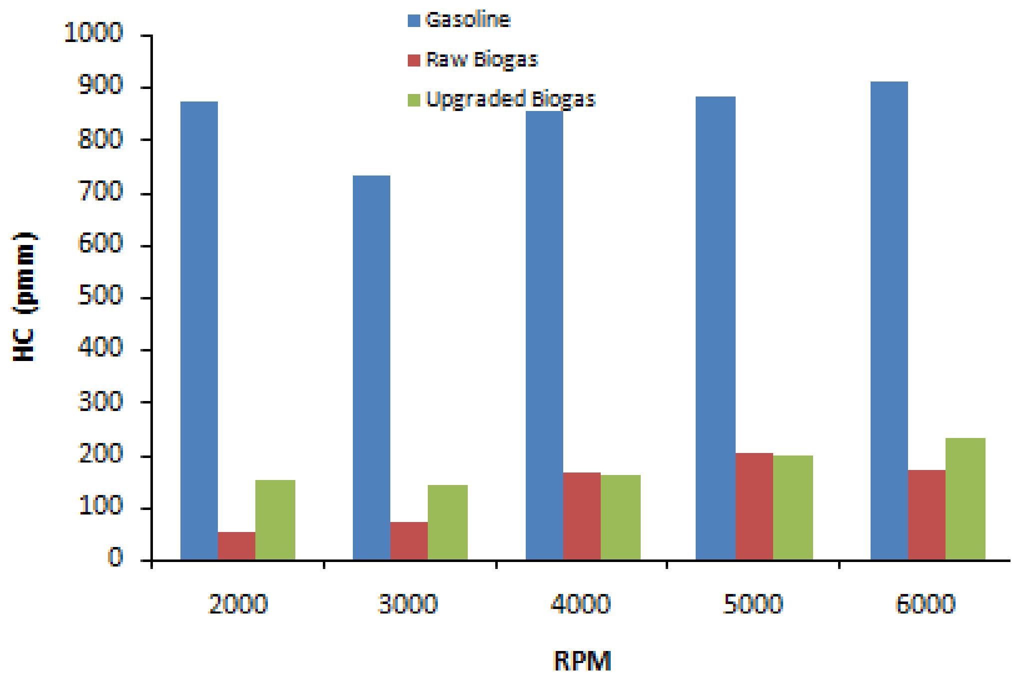

Figure 11: HC missions.

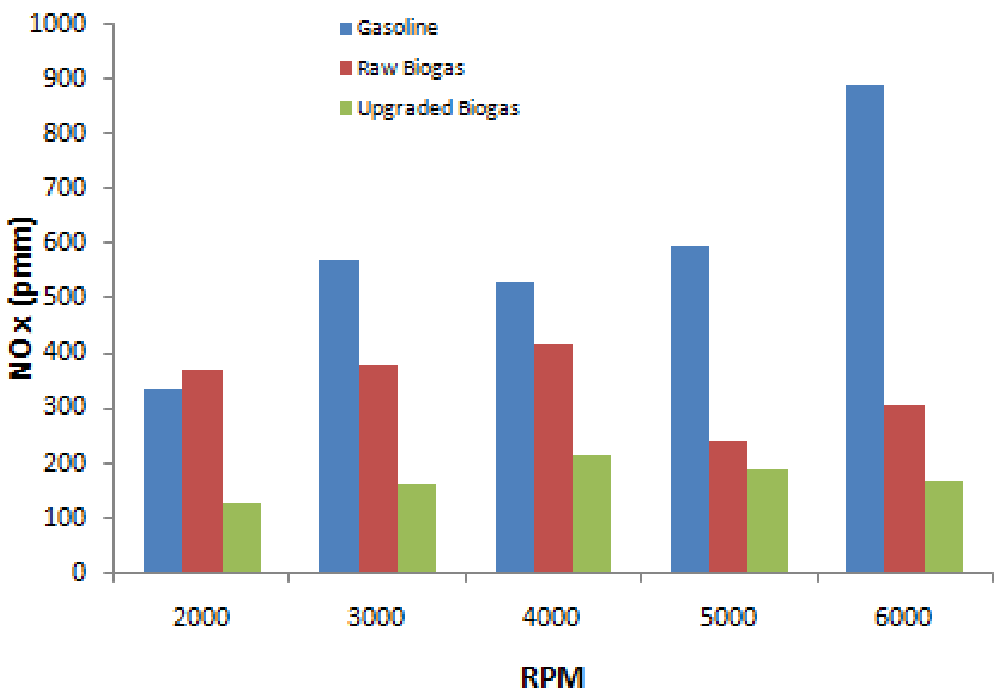

Figure 12: NOx Emissions.

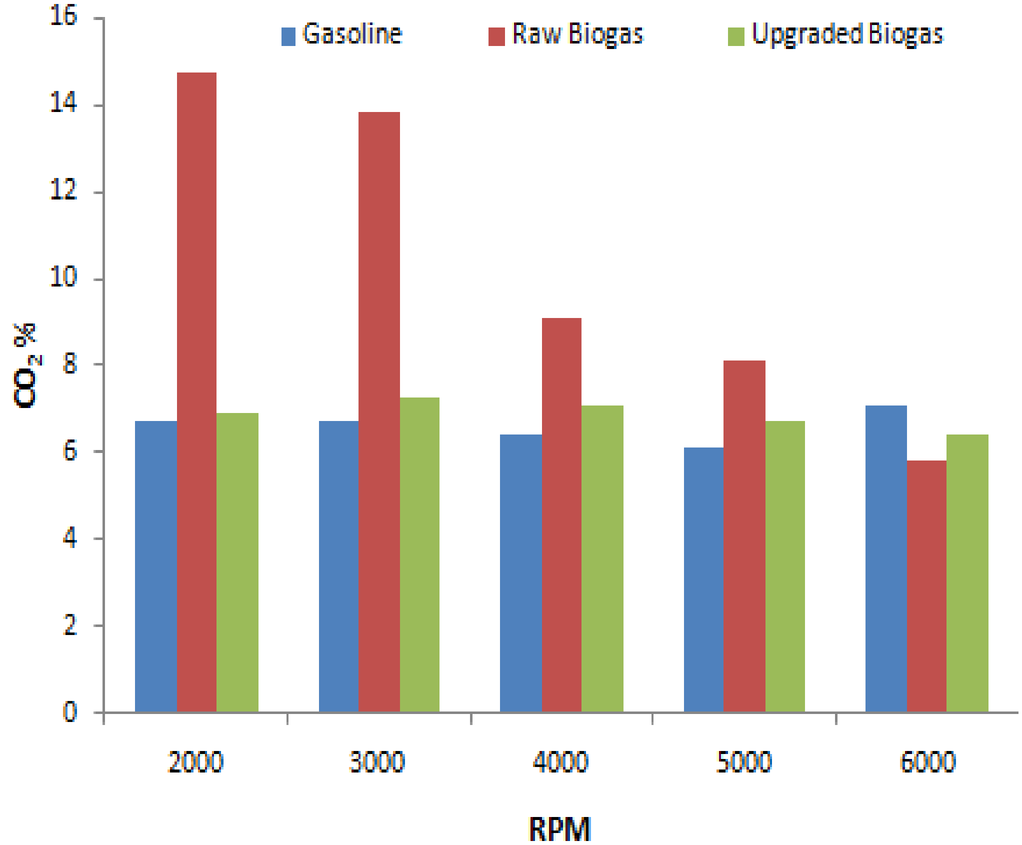

Figure 13: CO_2 emissions.

4. Conclusions

1. Biogas is a clean, environment friendly, renewable and sustainable source of energy that can be domestically produced from bio-wastes which is not only capable of solving local waste problem but has the potential to save carbon by using it as a vehicular fuel.
2. Raw biogas produced anaerobically can be upgraded to natural gas quality by removing its CO_2 and H_2S content using low cost water scrubbing technology. The upgraded biogas so obtained can be compressed and bottled to be used as CNG.
3. The study provides the guidelines to modify existing petrol engine to operate on biogas fuel.
4. A gas carburetor for modified engine is necessary for mixing of air and upgraded biogas in suitable ratio for easy cold start and acceleration without undue vibration and noise.
5. The performance of engine was found to be superior r when operating with upgraded biogas compared to raw biogas.
6. Use of upgraded biogas in vehicular engines reduces the release of CO, NOx, HC and CO_2 emissions thus it helps to protect the environment. The reduction in CO, NOx, HC and CO_2 emissions are of the order of 82%,69%,75% and 12% respectively if used in vehicular S.I engines
7. The price of domestically produce raw biogas and its up-gradation is still cheaper than the conventional gasoline fuel. This savings in fuel cost will help to lower the payback period for the purification unit and the gas kit pressure regulator.

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