Emission Analysis of Enriched Biogas Fuelled Stationary Single Cylinder SI Engine

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Abstract— This paper presents the emission results of a 7.5 hp Kirloskar Engine make TV 1 research engine which was converted into spark ignition mode and run on Enriched biogas and Petrol at compression ratio of 8 at constant narrow load range of 2 kg and rpm varying from 1100-1800. NOx level is decreased in Enriched Biogas mode from 97.72% decrease at 1100 rpm to 93.85% decrease at 1800 rpm. CO2 emission is increased from 3% to 4.1% (1100 rpm to 1800 rpm) for enriched biogas and for petrol 3.60% to 4.50% (1100 rpm to 1800 rpm) overall reducing 8% to 16% in comparison with petrol. Unburnt Hydrocarbon emission were seen lower in numbers with comparison to petrol engine. In petrol mode as the speed increased, CO emissions were also increased but in enriched biogas CO emission almost remains constant. From Richer to leaner mixture CO increases due to incomplete combustion.

Key words: Biogas, Methane Enriched Biogas, Petrol SI Engine, Compression Ratio, Alternative Fuel, Vehicular Fuel, Engine Performance, Engine Load, Engine Speed

I. INTRODUCTION

Insufficient nonrenewable energy source and increasing costs of fossil fuels have propelled many countries to assign the use of renewable energy techniques in internal combustion engines like, biogas, biomass, solar, hydrogen, ethanol etc. Before the year 2070, the world will deplete fossil fuels and hence the vast increase in biomass research [19, 20]. Engines exercised on spark ignition or compression ignition are tailored with conversion kits to operate on compressed natural gas and liquefied natural gas for practice in power plant, transportation etc. CNG (85 % methane and other gases) displayed the advantage of discounted exhaust emission and improved thermal efficiency in alternative fuel. Organic carbon deducted materials of plants and animals are called biomass. This biomass maybe converted by physical, chemical and biological process to biofuels. Anaerobic digestion of organic materials is a flammable gas called Biogas which is made of methane (60 %) and Carbon dioxide (40 %). In most of the countries, the chief biogas quality mark is the methane concentration, which should be at least 96 %, and carbon dioxide, which should not exceed 4 %. The Wobbe index is another indicator for chemical fuel that relies on higher heating value and can be used as a foundation for comparison between different gases. The concentration of sulphur hydrogen and water vapor in gases are also restrained because reactions of these chemical substances can corrode engines [15, 18]. Use of biogas technique can submit at least 10% national energy demand and approximately 50% to rural energy demand [1]. Developing countries like India can degrade their import bill by benefitting alternative fuel like biogas and befit self dependant because it has 300 million cattle population. At the moment India is on the second position in producing biogas immediately after China. Since the inception of biogas in 1930 roughly 2.5 million plants have been planted in India with a potential to seed over 10 million more. The Indian government looks at biogas technology as a medium to diminish rural poverty. The main biogas plants installed in the country are of types (i) floating drum type and (ii) fixed dome type plants [3]. A time of 15 days is sufficient for anaerobic bacteria to convert organic carbon material based biomass into biogas. Feedstock utilized for bio-methanation is usually animal and human wastes along with municipal wastes and agricultural crops [8].

For rising the calorific value and to impair unwanted components e.g. Water, CO2, H2S, which are damageable to utilization systems, it is absolutely necessary to rinse raw biogas and then improve it to a higher quality fuel. This process is called biogas rinsing and upgrading. Water scrubbing, chemical absorption, cryogenic separation, physical absorption, pressure swing adsorption, membrane technology, in- situ upgrading, and biological upgrading methods are few methods for biogas enrichment [2].

Parameter	Biogas from AD	Influence on biogas utilization
CH_4	60-70 %(mol)	
Heavy Hydrocarbons	0 %(mol)	
H_2	0 %(mol)	
CO_2	30-40 %(mol)	Decreasing calorific value, anti-knock properties of engines, corrosion
H_2O	1-5 %(mol)	Corrosion, damage due to formation of condensate and ice
N_2	0.2 %(mol)	Decreasing calorific value, anti-knock properties of engines
O_2	0 %(mol)	Corrosion
H_2S	0-4000 (ppm)	Corrosion, catalytic converter poison, emissions and health
NH_3	100 (ppm)	Emissions, anti-knock properties of engines, corrosion

Table 1: Composition of raw biogas [2]

II. BACKGROUND FOR BIOGAS AS AN ALTERNATIVE FUEL IN IC ENGINE

Raw biogas to be utilized as a vehicular fuel has to be enriched to at least 95% methane by volume and then it can be used in motor car altered to run on natural gas [4]. Biogas is potentially hazardous if given off directly into the ecosystem [5]. Liquid manure left unprocessed produces methane emissions that are twenty one times more powerful as a greenhouse gas than CO2. [4]. There is a double benefit by lowering fossil emissions from burning petrol, diesel and reducing methane emissions from waste manure. [4]. Biogas typically has a high self-ignition temperature so reducing auto ignition delays and hence resisting the phenomenon knocking but due to this reason it cannot be directly used in compression ignition engine [6, 15]. In biogas premixed charge diesel dual fuelled engine a mixture of air and biogas provided into engine, compressed and ignited by spray of fuel with a low self-ignition temperature like diesel or biodiesel, which is called a pilot fuel [15]. Biogas premixed charge diesel dual fuelled compression ignition engine yields lower energy conversion efficiency and higher breaks specific energy consumption at any load [7]. Propatham et al. [10] reported that enhanced swirl showed decrease in HC level and increase in NO level. Furthermore, it improved the performance including brake thermal efficiency and power output. Makareviciene et al. [11] concluded that when Exhaust Gas recirculation was turned off then excessive high air/fuel ratio results in higher fuel consumption and lower thermal efficiency, yet smokiness, HC, CO decreased and NO level increased. Lim et al. [12] summarized that, despite enriched biogas has a lower calorific value than the natural gases, NOx emissions were lower for the enriched biogas than for the natural gases and no noteworthy differences were seen in fuel economy between the gases in any of the driving cycle. Farzaneh-Gord et al. [13] studied the effects of storing CNG and found that the filling time required natural gas vehicle on-board cylinder to reach its final pressure (200 Bar) in the buffer storage system is 66 % less than the cascade storage system. Bordelanne et al. [14] developed prototype "Toyota Prius II Hybrid CNG Vehicle" and found that Green House Gas emissions from prototype are significantly lower than emissions of gasoline vehicles: approximately 17 % lower in the case of CNG Vehicle and 51 % lower in case of hybrid CNG vehicles. Moreover, in case of enriched biogas emission levels are lowered by 87 % in the case of the Toyota Prius CNG Hybrid prototype and also concluded 80% down green house gas emission in comparison with gasoline. Propatham et al. [15] modified diesel engine to run on spark ignition mode and found an increase in HC and NO level with rise in compression ratio. In addition lean misfire limit found with an equivalence ratio of 0.64 of compression ratio of 15:1 as opposed to 0.77 with a compression ratio of 9.3:1. Subramanian et al. [16] found no noteworthy difference in fuel economy between enriched biogas (24.11 km/kg) and CNG (24.38 km/kg). Exhaust emissions such as CO, HC and NOx are slightly higher with enriched biogas than CNG meeting Bharat Stage IV Emission Norms.

In light of above context, objective of the presented work was to determine the emission analysis of enriched biogas in (VCR) variable compression research engine converted into spark ignition engine which can run both on petrol and enriched biogas using necessary modification.

Properties	Petrol	Enriched Biogas
Chemical formula	C_8H_{18}	CH_4- 93 % CO_2 -4% H_2-0.06% N_2-2.94% H_2S-20 ppm
State	Liquid	Gas
Lower heating value (kJ/kg)	44000	42620
Octane rating	88-100	120-130
Cetane rating	-	--
Auto ignition temp.(K)	257	650-750
Stoichiometric ratio	14.7	17.2
Flash Point ° C	-42.77	-
Freezing Point ° C	-43	-
Boiling Point ° C	187-343	-82 to -161
Latent heat of vaporization kJ/kg	349	-
Density at 15^0 C, (kg/m^3)	720	0.9
Flame Speed (m/s)	4-6	0.34
Flammability Limits (volume % in air)	1.4-7.6	5-15

Table 2: Important Properties of Petrol and Biogas[9,16]

III. MODIFICATION OF RESEARCH ENGINE FROM DI TO SI MODE

Engine cylinder head for compression ignition mode was replaced with spark ignition mode. For working on enriched biogas mode, petrol fuel lines were removed and instead enriched biogas is supplied after passing through pressure reducer also known as Diaphragm pump with the help of flexible metal and rubber pipes. Control valve for influencing enriched biogas is placed before flowing into the venturi gas mixer. Enriched biogas fuel flow measurement was performed with the aid of weighing scale and stopwatch.

IV. EXPERIMENTAL DETAILS AND METHODOLOGY

A. *Experimental Engine Test Rig:*

Figure 1 show actual arrangement of experimental set-up of modified variable compression research engine in to enriched biogas fuelled engine. Figure 2 indicates schematic of experimental setup.

The experimental engine setup consists of following components:

- Variable Compression Research Engine: A four stroke, 7.5 HP, single cylinder, water cooled, multi fuel Kirloskar IC engine assembled by Apex innovation Pvt. Ltd. having injection timing at 25 ^{0}C before top dead center and connected to eddy current-type dynamometer for loading.
- Display instruments were used to capture readings of airflow, fuel flow, temperatures and loading measurements. Stand-alone type panel box consisting of air box, fuel flow measuring device were carefully calibrated before performing the experiment . Rota meters were used for cooling water and calorimeter exhaust water flow measurement.
- Compression ratio [Figure 3] of variable compression research engine was varied by unfastening allen bolts and then by spining CR adjuster nut upward or downward and finally tightening lock nut as shown in figure.
- Weighing scale for determining enriched biogas fuel consumption with fifty gram accuracy.

- Pressure reducer to alter enriched biogas from 200 bar to 1-2 bar.

Fig. 1: Photo of experimental setup showing engine, gas analyser, Gas cylinder and weighing scale

- Exhaust gas analyser: Five gas analyser for measuring emission of CO, HC, CO2 ,O2, NOx.
- Carburettor which also worked as venturi gas mixer to deliver petrol fuel and air to the petrol engine and enriched biogas and air to the enriched biogas mode engine.
- Air flow was supplied at standalone panel box with help of appropriate volume air box (Due to pulsating nature of air box) and recorded at manometer.
- Thermocouples for measurement of water and exhaust gas temperature.

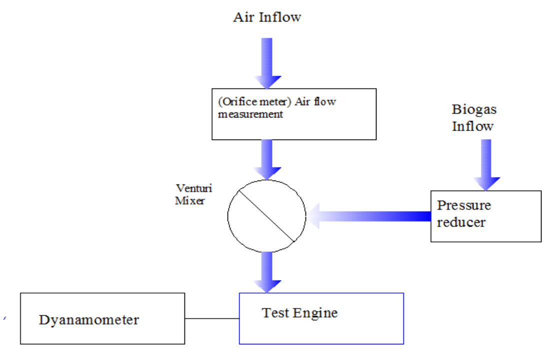

Fig. 2: Schematic Diagram of experimental setup

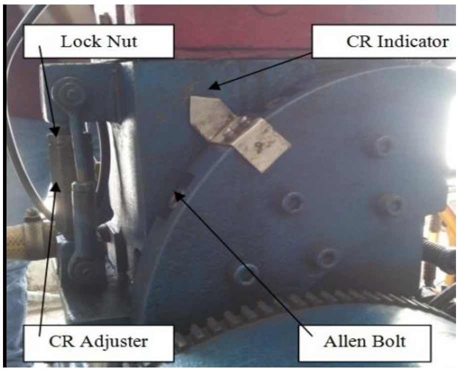

Fig. 3: Compression ratio setting

Item	Specification
Make & Model	Kirlosker Research Engines, TV1
Type	Four stroke, Water cooled, Petrol
No. of cylinder	One
Bore	87.5 mm
Stroke	110 mm
Compression ratio	6 to 10
Power rating	7.5 HP
Injection timing	$\leq$ ^{0}25BTDC
Valve Timing	Inlet valve opening (IVO): 4.5^0 before TDC Inlet valve closing (IVC): 35.5^0 after BDC Exhaust valve opening (EVO): 35.5^0 before BDC Exhaust valve closing (EVC): 4.5^0 after TDC
Load Capacity	0 to 20 kg

Table 3: Technical Specification

B. Experimental Procedure:

Engine investigation was performed with petrol first and then research engine modified for enriched biogas. During experimental work 1100 to 1800 rpm was differed using accelerator knob keeping narrow constant load at around 2 kg .

Measurement of exhaust gas emission was taken step by step.

Emission parameters like HC, CO, CO2, NOx,O2 were recorded using Quattro make five gas analyser of Aero equipments.

	Specified range	Accuracy Volume	Accuracy	Resolution
CO	0-10 %	0.06 %	3 %	0.01 %
HC	0-20000 PPM	12 PPM	5 %	1 PPM
CO_2	0-20 %	0.4 %	4 %	0.1 %
O	0-21 %	0.1 %	3 %	0.01 %
NO	0-5000 PPM	25 PPM	5 %	1 PPM
Lambda	0-9.99			0.001

Table 4: Technical Data for Gas Analyzer [17]

V. RESULTS AND DISCUSSION

The observation for exhaust emission performance on petrol and after modification on Enriched biogas for constant load conditions at 1100- 1800 rpm was taken. The results of emission parameters are presented below in detail.

A. CO emissios:

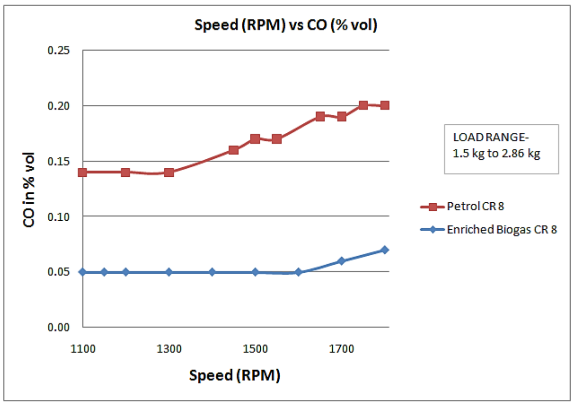

Fig. 4: Speed Vs CO emission at Lower Constant Load for both Petrol and Enriched Biogas.

It is cleared from Figure 4 that CO emissions are very low compare to petrol engine at constant narrow load condition and speed varying from 1100 to 1800 rpm. In petrol mode as the speed increased CO emissions were also increased but in enriched biogas CO emission almost remains constant. From Richer to leaner mixture CO increases due to incomplete combustion.

B. UHC Emission:

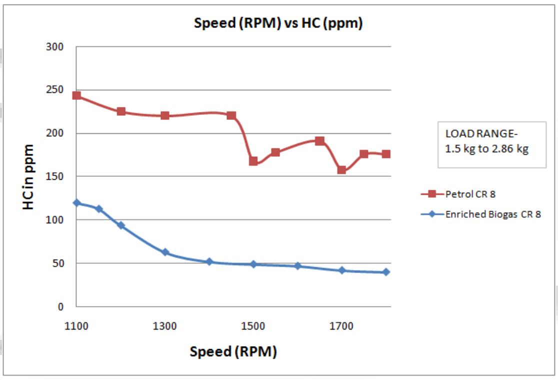

Fig. 5: Speed Vs HC at Lower Constant Load for both Petrol and Enriched Biogas.

Unburnt Hydrocarbon emission were seen lower in numbers with comparision to petrol engine. HC emission in both the case shows decreamental trend due to the fact that at starting rich mixture is went to the engine and as the engine warmed up lean mixture went to the combustion chamber. So from going from rich mixture to stoicheometric mixture and then Stoicheometric to lean mixture UHC emission decreses, and again start increasing respectively.

C. CO_2 Emission:

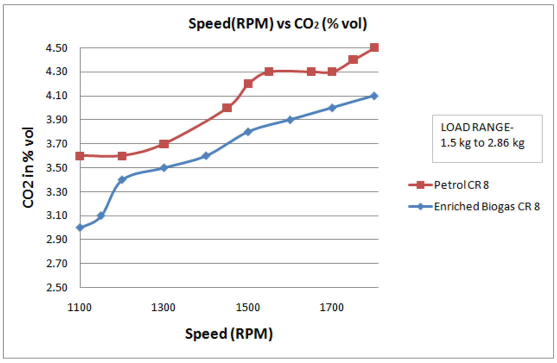

Fig. 6: Speed Vs CO_2 at Lower Constant Load for both Petrol and Enriched Biogas.

Figure 6 shows the variation of CO_2 emission with respect to speed. With increase in speed the CO_2 emission is increased from 3% to 4.1% for enriched biogas and for petrol 3.60% to 4.50% .

D. O_2 Emission:

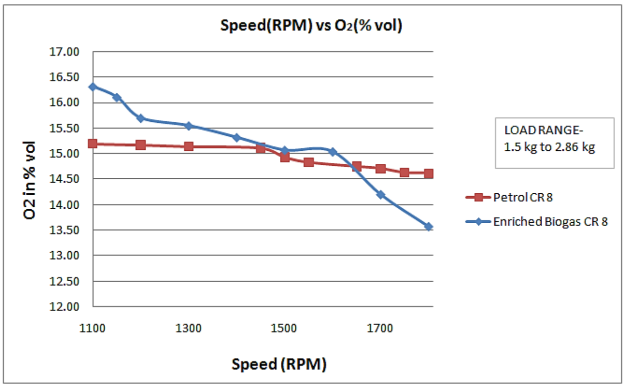

Fig. 7: Speed Vs O_2 at Lower Constant Load for both Petrol and Enriched Biogas.

At lower speed concentration of oxygen is very high in exhaust gases and with increase in speed oxygen concentration decreases fast. This is due to the fact that with increasing speed complete combustion starts and reduces O_2. Figure 7 shows the variation of O_2 with respect to speed. For minimum and maximum speed O_2 was 16.32% and 13.57% for Enriched Biogas. For Petrol, at minimum speed O_2 was15.19% and at maximum speed it was 14.62%.

E. NO_x Emission:

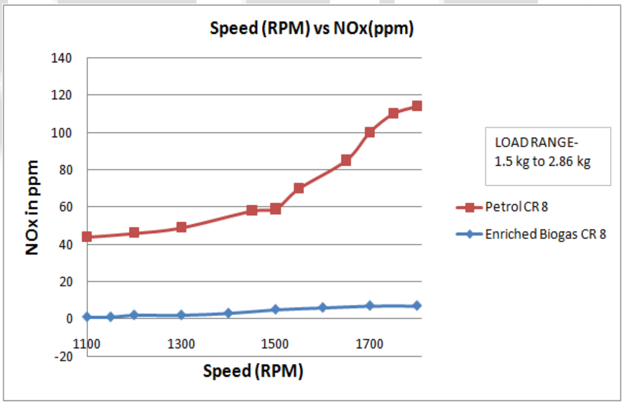

Fig. 8: Speed Vs NO_x at Lower Constant Load for both Petrol and Enriched Biogas.

Figure 8 Shows Speed Vs NO_x emission at constant load. NO_x is mainly dependent on High temperature and oxygen availability. Maximum exhaust temperature were 437.61^{0}C and 409.19^{0}C for petrol and Enriched biogas respectively. NO_x level is decreased in Enriched Biogas mode from 97.72% decrease at 1100 rpm to 93.85% decrease at 1800 rpm.

VI. CONCLUSION

Conclusion drawn on the basis of experimental investigation is:

The emission of NOx, CO2, HC, CO for Enriched biogas are lower than petrol operation. The NOx emission is reduced 93% to 97% and CO2 emission is reduced 8% to 16% at varying rpm condition as opposed to 75% to 200 % said in the literature survey. The HC is decreased 50% to

70% and CO decreased 64% to 65 % at constant narrow load range and increasing rpm.

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