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Dual Fuel Engine Operated with Hydrogen Enriched Producer Gas & Honge Biodiesel

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Abstract
Diesel engines are highly efficient and rugged due to their high compression ratio and are widely used in transportation, agriculture and power generation sectors. The main disadvantage of diesel engines is that they emit higher particulate matter and NO_x emissions. The ever-increasing cost of crude petroleum products, their rapid depleting nature and strict regulation norms laid down on tail pipe emission has necessitated search for suitable alternative, renewable and sustainable fuels for compression ignition (CI) engines in automotive traction and power generation sectors. Renewable and alternative fuels have several benefits compared with fossil fuels as they are renewable, sustainable and biodegradable and provide food and energy security and foreign exchange savings besides addressing environmental concerns and socioeconomic issues. By the current study, the main objective is to develop a dual fuel engine operated on low calorific value producer gas which is produced by the partial combustion of the woody biomass in a downdraft gasifier and suitable biodiesel (HONGE) in dual fuel mode. The producer gas will be enriched with hydrogen gas addition in varying proportion. A suitable carburetor will be designed to mix air, producer gas and hydrogen fuel combinations. Performance of the developed dual fuel engine will be optimized for improved brake thermal efficiency and reduced levels of smoke, HC, CO and NO_x emissions.

Key Word and Phrases
Diesel Engines, HONGE, Producer Gas, Brake thermal Efficiency, Carburetor, Emission.

1. Introduction

Diesel engines have become an important prime mover for power generation applications due to their high thermal efficiency and lower HC and CO emissions compared to gasoline engines. However, they emit higher smoke and nitric oxide (NOx) emissions. Many researches have conducted experiments to attain high thermal efficiency and lower emission characteristics of CI engines without compensating diesel consumption. An investigation was carried out on the utilization of biodiesel and its blended fuels (biodiesel obtained from unpolished rice and soya bean) and studied atomization and combustion characteristics CI engine. It was concluded that higher viscosity of the biodiesel encourages decreased injection velocity of biodiesel-blended fuels. In addition, comprehensive studies on the spray characteristics has been investigated. The biodiesel injection duration decreases slightly with decreased biodiesel content in the blend. Fuel injection duration drops, and peak injection rate increases with appropriated fuel injection pressure and combustion duration of biodiesel was found to be relatively longer than diesel [1]. CI engines possess better thermal efficiency as well as power output with increased levels of soot and NOx emissions. CI engines have an ability to utilize high-quality renewable fuels that can be obtained efficiently from biomass of different origin. Biodiesels are clean fuel, it addresses environmental and socio-economic issues. In addition they also provide energy and food security [2]-[6]. Experimental tests were conducted on single cylinder diesel engine using biodiesel and blends and effect of different engine parameters on engine performance were investigated [2], [3], [7]-[9]. A study was conducted on investigation of combustion and emissions characteristics of sea lemon oil as a fuel. The results reveal that increase in the injector opening pressure from the rated value diesel 170 bar to 190 bar. Results in a significant improvement in performance and emissions characteristics with fuel as Sea lemon oil due to better spray formation and also increases brake thermal efficiency from 27.3%-29.1% [10]. To reduce PM and NO_x emission from diesel engines, study was performed using CNG DFC as a biodiesel fuel and considering the system as low temperature combustion technology for simultaneous reduction of pollutants which includes investigation on effect of pilot injection pressure on the characteristics of engine emission in a single cylinder diesel engine. Emission characteristics of a biodiesel engine operating with various percentage of hydrogen enriched gas with diesel (5%, 10%,20%, 30%, 40%, and 50% by volume).Results reveal that increase in the concentration of hydrogen with base diesel fuel reduces combustion time and ignition lag and the amount of CO released from the emission is reduced [11].The speedy depletion of underground fossil fuels and environment degradation due to combustion of fuels resulted in tremendous attention in finding suitable alternative fuels. Therefore, it is essential to evaluate the feasibility of alternative fuels. Rapid progress in the direction of using biodiesel and producer gas for compression ignition will be undertaken in order to become independent of diesel. Hence present work evaluates such a combination of fuels towards total elimination of diesel fuel [12].

By the present research an attempt is made to develop dual fuel engine operated on low calorific value gas called producer gas produced by partial combustion of the woody biomass in a downdraft gasifier and Honge oil methyl ester (HOME) biodiesel in a duel fuel mode. A suitable carburettor is designed to mix air, producer gas and hydrogen fuel combination. Diesel engine is suitably changed to operate in dual fuel mode with HOME biodiesel and producer gas fuel combinations. In the present work, performance, emission and combustion characteristics of a single cylinder four stroke diesel engine operated in dual fuel mode using HOME biodiesel and producer gas. Finally the results obtained were compared with base line data.

2. Experimental Setup

The engine tests were conducted on a computerized CI engine test rig. It is of Kirloskar, TV1 engine and made up of single cylinder, 4-stroke, water cooled, and high-speed engine. The engine is coupled directly with eddy current dynamometer.

Fig. 1 Experimental Setup

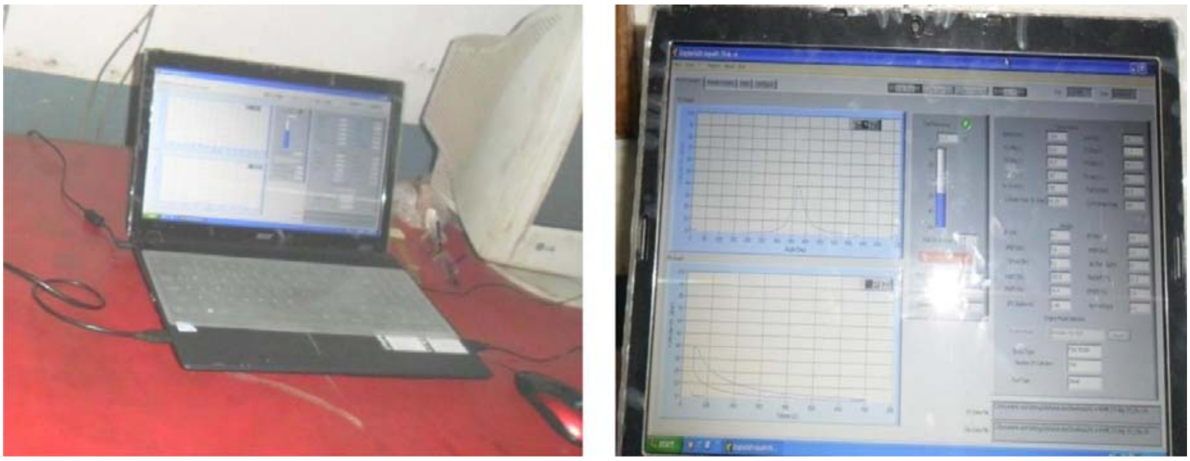

Fig. 2 Data Acquisition system

The engine and dynamometer were interfaced to a control panel and the it is connected to a digital high-speed computer. The computer software "Engine soft" was used in digital computer. The computer is used for recording the test parameters like fuel consumption, brake power, indicated power, brake thermal efficiency, BMEP, IMEP, volumetric efficiency, mechanical efficiency, EGT and peak pressure etc.

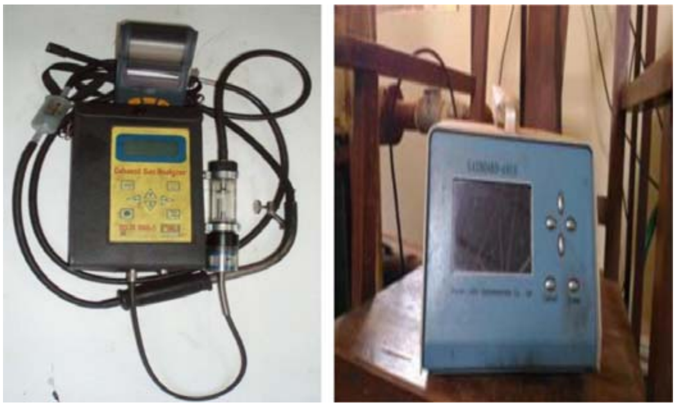

Fig. 3 HC & CO analyser **Fig. 4** Exhaust gas analyser and Smoke-meter

Table 1 Specifications of the engine

Make and Model	Kirloskar, TV1
No. of Cylinders	One
Orientation	Vertical
Cycle	4 Stroke
Ignition System	Compression Ignition
Bore X Stroke	87.5mm X 110mm
Displacement Volume	660 cc
Compression Ration	17.5 : 1
Arrangement of valves	Overhead
Combustion Chamber	Open Chamber (Direct Injection)
Rated Power	5.2 kW (7 HP) @1500 rpm
Cooling Medium	Water cooled

Table 2 Specifications of the down draft gasifier

Type	Downdraft gasifier
Supplier	Ankur Scientific Energy Technologies Pvt. Ltd., Baroda.
Rated capacity	62735 kJ/h
Rated Gas flow	15 Nm^3/h
Average gas calorific value	5-5.6 MJ/m^3
Rated woody biomass consumption	5-6 kg/h
Hopper storage capacity	40 kg
Biomass size	10 mm (Minimum) 50 mm (Maximum)
Moisture content (DB)	5 to 20%
Typical conversion efficiency	70-75%
Typical gas composition	$CO=19\pm3\%$, $CO_2=10\pm3\%$, $N_2=50\%$, $H_2=18\pm2\%$, CH_4=upto 3%

2.1 Proposed Design of Carburettor for Hydrogen-producer Gas Mixture

2.2.1. Design of Gas Venture

This section discusses on the design of gas carburettor used for the mixing of air and producer gas at stoichiometric ratio.

Step I: Determination of the volumetric intake of engine

Engine bore (D): 8.75 cm
Engine stroke (S): 11.0 cm
Rated speed (N): 1500 rev/min.
Maximum speed (120% of rated speed) (N'): 1800 rev/min.
Displacement volume = 661cc/cycle
Maximum (air + gas) intake under extreme conditions = $\frac{V_s * N_1}{10^6 * 2 * 60}$
(Assuming 100% volumetric efficiency) = **0.009915 m^3/s**

Step II: Determination of mean intake velocity

Intake manifold diameter (D_i) = 0.029m
Cross sectional area of intake manifold (A_i) = 0.6605198 * 10^{-3} m^2
Therefore mean intake velocity

$$C_i = \frac{\text{Volume flow in } m^3/s}{\text{cross sectional area } m^2} = \mathbf{15.0109\ m/s}$$

Step III: **Determination of the air and gas quantities**

Stichometric air to fuel ratio = 0.9044 N m^3/ N m^3
Stichometric air to fuel ratio at 30^0 C and 710 mm of Hg (at Hubli) = 0.9843332 m^3 of air / m^3 of gas.
Therefore maximum gas intake = **0.0049966437 m^3/s**

Similarly maximum air intake = **0.00589848 m^3/s**
Density of producer gas at normal conditions = 1.1909 kg/m^3
Density of producer gas at 30^{0}C and 710 mm of Hg = 1.2961549 kg/m^3
Density of air at 30^{0}C and 710 mm of Hg = 1.0885208 kg/m^3
Mass flow rate of gas, m_g = **0.0064763676 kg/s**
Mass flow rate of air, m_a = **0.0064205311 kg/s**

2.2.2 Schematic diagram of Gas Venture:

Figures 5 and 6 shows the standard venture with dimensions and cross sectional view.

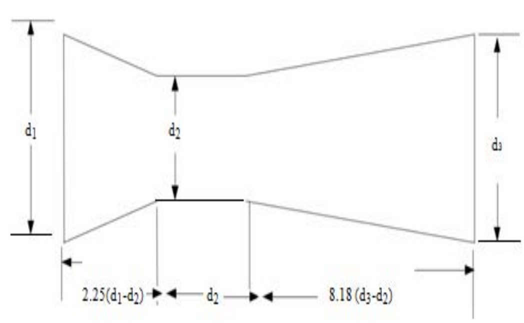

Fig. 5 Dimensions of a standard venture

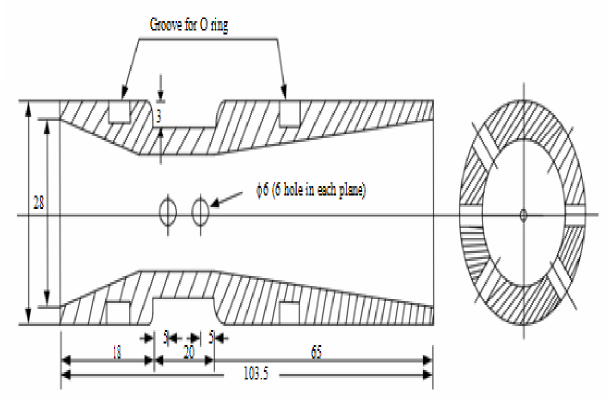

Fig. 6 Cross sectional view of venture

Table 3 Properties of diesel, HOME

Sl No	Properties	Diesel	HOME
1	Viscosity (cSt at 40 °C)	2-3	5.3
2	Flash point (°C)	56	187
3	Calorific Value (kJ/kg)	45000	39798
4	Density (kg/m3)	830	909
5	Cetane Number	45-55	----
6	Cloud Point (^{0}C)	15	-1^0 C
7	Pour Point (^{0}C)	1	-8^{0}C
8	Carbon Residue (%)	0.1	0.01
9	Type of oil	Fossil fuel	Non edible

Table 4 Properties of hydrogen

Property	Hydrogen
Density at 1 atm and 300k (kg/m3)	0.082
Stoichiometric composition of air (% by volume)	29.53
No. of moles after combustion to before	0.85
Higher heating value (MJ/kg)	141.4
Lower heating value (MJ/kg)	1119.7
Higher heating value (MJ/m3)	12.10
Lower heating value (MJ/m3)	10.22
Combustion energy per kg of stoichiometric mixture (MJ)	3.37
Kinematic viscosity at 300k (mm^2/sec)	110
Thermal conductivity at 300 (mW/mK)	182
Diffusion coefficient in to air at NTP (cm^2/sec)	0.61
Flammability limits (% by volume)	4.75
Minimum ignition energy (mJ)	0.02
Laminar flame speed at speed at NTP (m/sec)	1.90
Adiabatic flame temperature (K)	2318
Auto ignition temperature (K)	858
Quenching gap at NTP (mm)	0.64
Stoichiometric fuel air mass ratio	0.029

Table 5 Stoichiometric air requirement calculation

Analysis	Fraction	Stoichiometric air ratio Nm^3/Nm^3	Air requirement
Carbon Monoxide	0.24	2.38	0.24*2.38=0.5712
Hydrogen	0.10	2.38	0.10*2.38=0.238
Methane	0.01	9.52	0.01*9.52=0.0952
			Total =0.9044

Table 6 Determination of density of producer gas

Analysis	Fraction present	Density kg/m^3	Density of Producer Gas kg/m^3
Carbon Monoxide	0.24	1.250	0.24*1.250=0.3000
Hydrogen	0.10	0.090	0.10*0.090=0.0090
Methane	0.01	0.717	0.01*0.717=0.0072
Carbon Dioxide	0.08	1.977	0.08*1.977=0.1582
Nitrogen	0.57	1.257	0.57*1.257=0.7165
	1.00		**Density =1.1909**

3. Results and Discussions

This section presents the results and discussion on the performance of dual fuel engine fueled with producer gas enriched with hydrogen and HOME respectively. In order to study the effect of gas flow rates hydrogen percentage in producer gas was varied from 2 to 8 LPM respectively. For the experimental investigations carried out on the dual fuel engine, the injection timing was maintained constant at 27^{o}BTDC, while injection pressure of injected liquid fuels were kept constant at 240 bar.

3.1 Brake Thermal Efficiency (BTE)

Brake thermal efficiency (Fig. 7) is found to be higher for diesel-producer gas dual fuel mode compared to HOME - producer gas operation over the complete load range. Higher viscosity and lower energy content of biodiesel compared to diesel which makes atomization difficult and all together results in to decreased BTE. Addition of hydrogen increases the BTE of the HOME-PG. Since hydrogen has very high calorific value, hence BTE increased with increased flow rate of hydrogen.

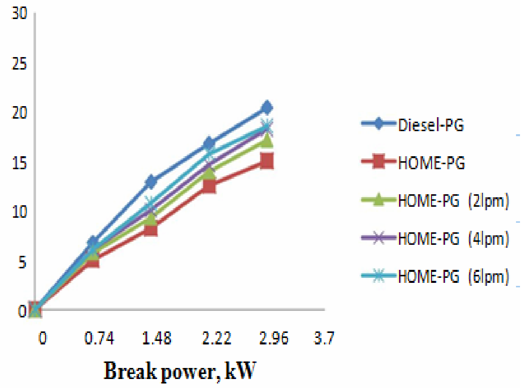

Fig. 7 Variation of brake thermal energy with brake power

3.2 Smoke Opacity

The smoke levels were found to be lower for Producer gas- diesel dual fuel operations compared to HOME - Producer gas over the complete load range (Fig. 8). Heavier molecular structure of the injected biodiesel compared to diesel results in higher smoke levels. Further, reduced oxidation caused by the replacement of oxygen is also responsible. But, when hydrogen is added to HOME-PG combination, the smoke opacity is reduced. With increased hydrogen flow rate, the smoke opacity decreased due to lower Carbon-to-Hydrogen (C/H) ratio and lower molecular weight of hydrogen supply.

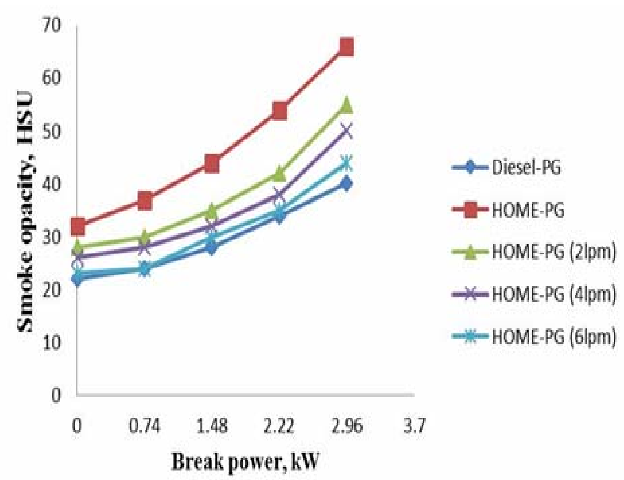

Fig. 8 Variation of smoke opacity with brake power

3.3 Hydrocarbon Emission

The emission of hydrocarbons is minimal for the diesel-producer gas compared to HOME-PG over the entire load range (Fig. 9). When hydrogen is added to HOME-PG dual fuel mode the emission of hydrocarbons from the exhaust tail pipe decreases. As the flow rate of hydrogen to engine intake increased due to its higher calorific value enables complete combustion of the fuel and thereby the HC emission decreases.

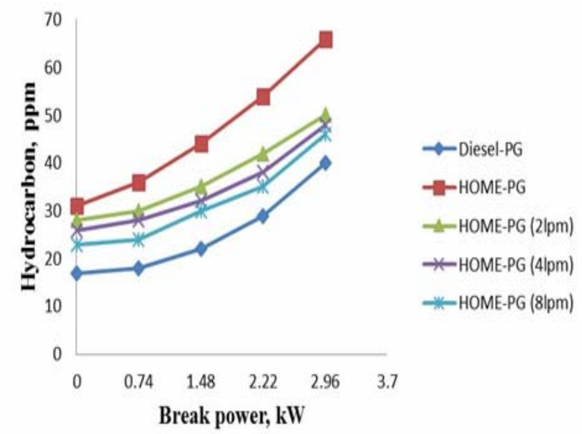

Fig. 9 Variation of hydrocarbon emission with brake power

3.4 Carbon Monoxide

The emission of carbon monoxide is lower for the diesel-producer gas when compared to HOME-PG over the entire load range (Fig. 10). This is because the producer gas being common the properties of the injected pilot fuel makes the difference in the emission values. Lower emmissions of CO is the direct result of increased flowrate of hydrogen which enables complete combustion of the fuel.

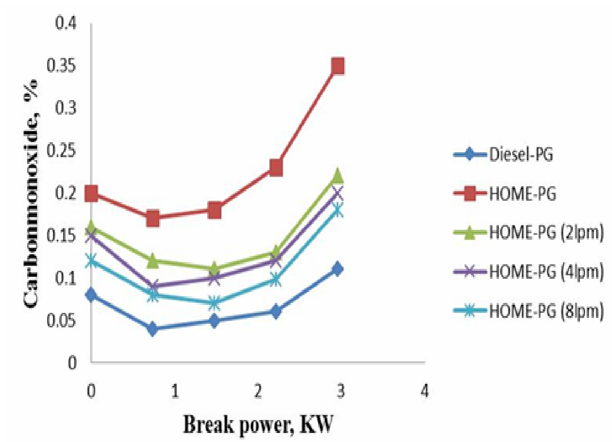

Fig. 10 Variation of carbon monoxide with brake power

3.5 Nitric Oxide (NO_X) Emission

The emission of nitric oxide is less for HOME-PG compared to diesel-producer gas over the entire load range (Fig. 11). When hydrogen is added to HOME-PG dual mode the emission of the nitric oxide is increased. As the hydrogen flowrate increases, the emission of nitric oxide gradually increases. Since hydrogen has higher calorific value it enables complete combustion of the fuel due to which the combustion temperature increases. Due to this increased temperature the emission of nitric oxide increases.

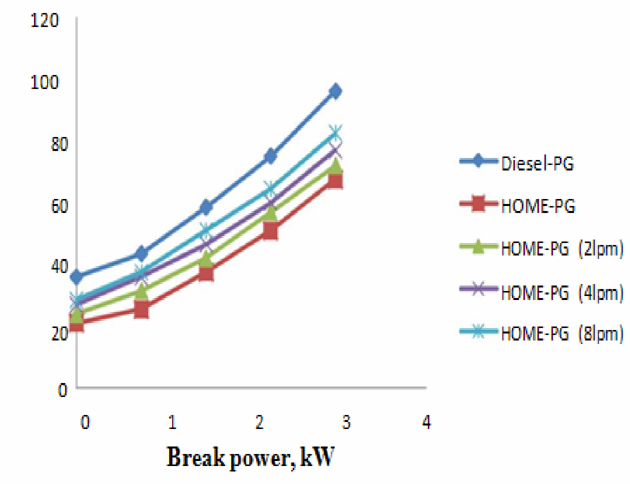

Fig. 11 Variation of emission of nitric oxide with brake power

4. Conclusions

From the rigorous study it is concluded that the use of Hydrogen enriched producer gas as an alternative fuel along with HOME can perform better than HOME alone next to diesel fuelled engine. Furthermore, from the emission records it is observed that for higher amount of hydrogen addition there is reduction in HC, CO and Smoke from engine exhaust but NOx emission is higher for the same amount of hydrogen. This can be eliminated by installing a suitable catalytic convertor in the exhaust system which converts harmful combustion products into harmless by-products. Further work on the engine could involve modification with use of various biodiesels like rice bran oil and neem seed oils respectively. Such higher volatile biodiesels can be either directly injected into the engine manifold or can be blended by mixing with diesel. Incorporation of ECU (electronic control unit) in the existing system can increase the engine performance and can simultaneously reduce both smoke and NOx emissions. By further research and study on the subject the use of diesel can be completely eliminated with advanced engine facilities.

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