Comparative Study of Hydrogen, Biodiesel, CNG & Mixture of Hydrogen & Natural Gas as Fuels in Internal Combustion Engine

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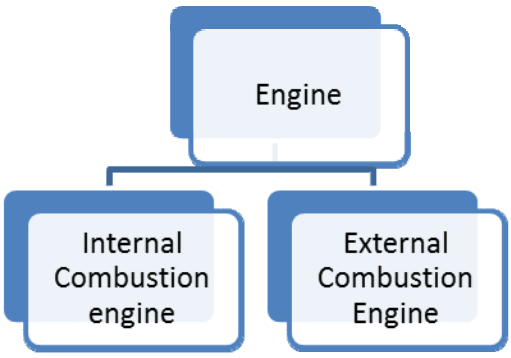
Abstract - Due to increase in population and rapid industrialization there is increase in consumption of conventional fuels. Due to this fossil fuels are on the verge of extinction. The tremendous use of these fuels has created a harmful impact on environment. This led to a need for searching and developing alternate fuels to meet the increasing demands. Researchers conducted experiments to develop new fuel. This paper emphasizes on the comparative study on alternative fuels such as Mahua biodiesel, Hydrogen & Gasoline fuel, Eucalyptus biodiesel, Natural Gas & Hydrogen fuel, Compressed Natural Gas as fuel. It was found that pure biodiesel is not effective but when biodiesel is blended the properties are enhanced. Hydrogen can be used as fuel for internal combustion engine with changes in combustion chamber. Hydrogen & Natural gas can be used as fuel but for efficient performance the % of Hydrogen in Natural gas should be more than 20%. Eucalyptus Biodiesel & Mahua Biodiesel differs slightly in their method of production & their properties. The study was made on various aspects such as BTE, BSFC, Exhaust Gas Temperature & NOx & HC emissions. Results were calculated based on their performance.

Keywords: Mahua biodiesel, Eucalyptus Biodiesel, Performance, Blending

I. INTRODUCTION

Due to limited reserves of conventional energy sources there was need to search and develop non-conventional fuels. Engine is the heart of mechanical system. Engine converts one form of energy into mechanical energy. We classify engine into various types based on their working, appearance etc. But here we are concerned with the engine which is used to drive an automobile.

Therefore we classify engine as given below



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We define combustion as the process of exothermic reaction taking place due to burning of fuel. In automobiles we are concerned with internal combustion engines. In internal combustion engine combustion of fuel takes place inside combustion chamber in presence of air. Due to this chemical reaction heat energy is released. This energy is used to drive the vehicle. The fuels that we use in IC engine are on the verge of extinction due to this we should use alternative fuels in IC engine by making some modifications in engine so as to run the engine with that fuels.

Fuels:

We describe fuel as a substance which is made to react to release chemical energy for performing useful work.

Fuels for IC engine are classified as below

1. *Conventional Fuel*
   a. Crude Oil Derived
      i. Petrol
      ii. Diesel
   b. Other sources
      i. Coal
      ii. Wood
      iii. Tar sands
      iv. Shale
2. *Alternate Fuels*
   a. Petroleum derived
      i. CNG
      ii. LPG
   b. Biomass derived
      i. Ethanol
      ii. Biodiesel
      iii. Biogas
      iv. Electricity
      v. Hydrogen

Conventional Fuels:

These fuels are fossil fuels. Fossil fuels are the fuels which are formed by anaerobic decomposition of buried organisms. Petrol & Diesel that we use are derived from crude oil

1 Diesel

Properties of fuel	Unit	Diesel
Kinematic Viscosity at 40°C	cSt	4.57
Specific gravity at 15°C	-	0.8668
Flash point	°C	42
Fire point	°C	68

Pour point	°C	-18
Cloud point	°C	-3
Cetane Index	-	50.6
Calorific Value	KJ/Kg-K	42850

Diesel is extracted from fractional distillation of crude oil. The quality of diesel is calculated based on Cetane Number. Cetane number is percentage of Cetane present in mixture of Cetane & 1-Methylnapthalene. Higher the Cetane number better ignition characteristics.

Advantages

- It is used as fuel in spark ignition engines
- It has high compression ratio than Gasoline. It has compression ratio of 14:1 to 18:1
- It has higher ignition Temperature

Disadvantages

- Cold starting of engine running on diesel is difficult.
- Emission is not clean.

2 Biodiesel

Biodiesel is made from Non-edible sources such as Mahua oil, Eucalyptus Oil etc. Biodiesel is obtained by transesterification process as by product of glycerol. But rather than using pure biodiesel it is blended to improve its properties.

Advantages

- It has low cost.
- Cetane number is high.
- Clean Smoke is produced.
- It is biodegradable.

3 Hydrogen

Hydrogen is also being used as fuel with some modifications. Methods of production include Electrolysis etc.

Advantages

- Hydrogen mixture burns at a faster rate than gasoline mixture.
- Clean Exhaust is produced.
- Self-ignition Temperature is high.

The above listed fuels can be used as a substitute for diesel & gasoline fuels.

II. REVIEW OF SOME RESEARCHERS

1 Swarup Kumar Naik (Mahua biodiesel)

Materials-Mahua oil, Dimethyl Carbonate, Test Engine

Engine Specifications

Particulars	Description
Engine Type	4 stroke single cylinder water cooled diesel engine
Bore diameter	80 mm
Stroke length	110 mm
Compression ratio	16.5:1
Rated power	3.67kW
Rated speed	1500 rpm
Dynamometer	Eddy type

Experimental Procedure

Mahua oil is heated up to 110°C and then transesterification is done .Biodiesel and glycerol is obtained biodiesel is washed with distilled water to remove acid. To remove moisture it is heated above 100°C .Thus clean Mahua biodiesel is obtained.

Performance & emission characteristics were studied by comparing Mahua oil methyl ester and diesel. Number of tests were carried out such as specific gravity, flash point, fire point, pour point, cloud point, ash point etc. Ash was extracted to measure ash content. Speed was kept constant at 1500 rpm. Both fuels were allowed to pass through engine then η_{bth}, $\eta_{ith,}$ bsfc, exhaust gas temp were calculated.

Properties of fuel	Unit	Diesel	Mahua biodiesel
Kinematic Viscosity at 40°C	cSt	4.57	5.39
Specific gravity at 15°C	-	0.8668	0.8712
Flash point	°C	42	157
Fire point	°C	68	183
Pour point	°C	-18	2
Cloud point	°C	-3	16
Cetane Index	-	50.6	51.2
Calorific Value	KJ/Kg-K	42850	42293

Result

1 Brake thermal efficiency-

The following results of BTE were obtained. In the initial stage BTE increased with increase in load up to 80% but it decreases at full load. Here Diesel has highest BTE than blended biodiesel.

The Table shows BTE for full load

Fuel used	BTE in%
Diesel	30.09
B100	26.63
B95	28.01
B90	29.74
B85	29.97

2 Brake specific fuel consumption-

It is observed that BSFC first decreases up to 80% of load then it increases for full load. Pure Biodiesel has highest BSFC .But this can be improved by using additive.

Following table shows BSFC of Diesel & Test fuels

Fuel used	BSFC in Kg/KW-hr
Diesel	0.387
B100	0.556
B95	0.503
B90	0.4993
B85	0.4104

3 Exhaust gas temperatures-

EGT increases with increase in load for diesel and test fuels. Diesel has minimum EGT than other test fuels. Whereas it is maximum for pure biodiesel.

Following table shows EGT of Diesel & Test fuels

Fuel used	Temp in °C
Diesel	439
B100	489
B95	467
B90	454
B85	451

4-Hydrocarbon & NOx Emission

It is observed that HC emission increases with load for all test fuels. Biodiesel produces low HC emissions as compared to diesel. But with increase in additive HC emission increases because of low cylinder pressure, temperature causing low burning rate.

NO_x increases with increase in temperature and increases with increase in engine load. It is highest for pure biodiesel because of high oxygen content resulting in complete combustion. With increase in additive mixture NO_x emission decreases.

Table shows NO_x & HC emissions.

Fuel used	Amount of HC in ppm	Amount of NO_x in ppm
Diesel	55.67	573
B100	31.093	1059
B95	41.22	988
B90	39.87	967
B85	34.63	836

Conclusion-

- BTE increases with increase in % of additive in Mahua biodiesel .BTE is less for pure biodiesel.
- BSFC is highest for pure biodiesel but decreases with increase in additive in Mahua biodiesel.
- EGT is highest for pure biodiesel but decreases with increase in additive in Mahua biodiesel.
- HC emissions are highest for diesel and are low for pure biodiesel. With increase in additive in Mahua biodiesel emissions decrease.
- NO_x emission is highest for pure biodiesel but decreases with increase in additive in Mahua biodiesel.

2 Erol Kahraman (Hydrogen & Gasoline fueled SI Engine)

Materials-Engine, Dynamometer, Control Panel, Hydrogen regulator, Exhaust gas analyzer.

Engine Specifications

Particulars	Description
Engine Type	4 stroke 4 cylinder SI engine
Bore diameter	73 mm
Stroke length	71.5 mm
Compression ratio	8.8:1
Power	60 HP at 5600 rpm
Torque	89 Nm at 3400rpm
Ignition	Distributor type, static advance
Fuel feeding	Solex 2 barrel carburetor
Swept volume	1197 cc
Exhaust	Standard muffler with silencer

Experimental Procedure-

In this experiment researcher took 4 cylinder 4 stroke SI engine. The setup is such that engine is connected to dynamometer which is connected to control panel. From various steel bottle hydrogen comes in and regulator is placed to control flow of hydrogen. Hydrogen is initially compressed up to 20 MPa Regulators are present to drop pressure up to 300 kPa and then to atmospheric pressure. Further arrangement consists of carburetor, intake manifold & exhaust manifold. To exhaust manifold Exhaust Gas analyzer is attached.

The properties of hydrogen and gasoline are

Property	Hydrogen	gasoline
Density at 1atm,300K	0.082 kg/m^3	5.11 kg/m^3
Stoichiometric composition in air (% by volume)	29.53	1.65
LHV	119.7 MJ/Kg	44.79 MJ/Kg
Combustion Energy in terms of stoichiometric mixture	3.37 MJ/Kg	2.79 MJ/Kg
Auto ignition Temp	858 K	500 K-750 K

Special care was taken by addition of spray nozzle of water to avoid back-fire operation. Ignition timing was set to 10^0 before TDC. The engine speed was maintained at 2600 to 3800 rpm. Gasoline experiments were performed after hydrogen experiments at operating temperature. Various tests were performed. All this results were in comparison with engine speed

Result

1 Brake thermal efficiency-

It was observed that BTE of Hydrogen fuel is greater than that of Gasoline fuel. At higher speed BTE of Hydrogen fuel is greater than Gasoline fuel.

2 Brake Torque-

It was observed that at the start Brake Torque of Hydrogen is less than Gasoline .But as speed increases Brake Torque of Hydrogen increases.

3 Brake Power-

The power output of Hydrogen is less than that of gasoline at low speed & same size engine. But after 3100 rpm power of Hydrogen Engine increases.

4 Brake mean effective pressure-

BMEP of hydrogen fuel increases at 3100 rpm In case of gasoline fuel BMEP decreases with increase in speed.

5 Exhaust gas temperature-

EGT increases with increase in speed in case of Hydrogen fuel but it is less than EGT of Gasoline fuel. It is due to cooling effect of water.

6 NOx Emissions-

It was observed that there was appreciable decrease in NO_x emission in case of Hydrogen fuel.

7 CO, CO2 & HC Emissions-

As speed increases CO emission vanishes in case of Hydrogen fuel. CO_2 emissions are also low for hydrogen .The emissions are due to combustion of lubricating oil. Due to chocking more HC is present.

Conclusion-

- With increase in speed above 2600 rpm backfiring is prevented.
- Power loss in case of hydrogen fueled engine is less at high speed.
- NO_x Emissions are also considerably reduced.
- CO, CO_2 & HC Emissions are very less.
- Hydrogen can be used as good engine fuel with appropriate changes in combustion chamber.

3 Puneet Verma (Eucalyptus Biodiesel)

Materials-Samples of Eucalyptus oil Single cylinder diesel engine of 4.8kW power &speed 1500 rpm.

Experimental Procedure-

This paper gives a focus on use of Eucalyptus oil as fuel. Since Eucalyptus was available in India from 18th Century efforts were made to use it as fuel.

Transesterification reaction is done. Catalyst was used to speed up the reaction. Biodiesel was separated with magnetic separation method for purification. Yield was found to be approximately 86 %. The properties of Eucalyptus oil & diesel are similar therefore we can use Eucalyptus oil in diesel engine.

Readings were taken by first using pure diesel & then by using blends such as B10, B30, B50, & B100. BSFC & BTE is calculated.

Result & Conclusion-

- As volume of biodiesel is increased in blend calorific value decreases therefore fuel consumption increases.
- B10 is acceptable because it has low BSFC.
- BTE increases with increase in blend.
- Clean smoke was produced using Eucalyptus biodiesel.
- CO & HC emissions are also less.
- This all points suggest that Eucalyptus biodiesel can replace diesel.

4 Zuohua Huang (Natural Gas & Hydrogen)

Materials- 3 Cylinder compressed natural gas (CNG) spark-ignited (SI) automotive engine, natural gas & hydrogen were used as fuel.

Property	Hydrogen	Natural gas
Density at 1atm,300K	0.082 kg/m^3	0.754 kg/m^3
Stoichiometric A/F ratio (% by volume)	2.387	9.936
LHV	119.7 MJ/Kg	43.726 MJ/Kg
Conductivity at 300K	182 W/mK	34 W/mK
C/H ratio	0	0.25
Cetane number	-	127
Quenching distance	0.64 mm	2.03 mm

Engine Specifications-

Particulars	Description
Bore diameter	68.5 mm
Stroke length	72 mm
Compression ratio	9.4:1
Rate of Power	26.5kW
Speed	5500 rpm
Displacement	796mL

Experimental Procedure-

By using various fractions of hydrogen & natural gas blends were prepared. The types of fuels used for experiment were pure natural gas, fuel blend with 90% natural gas &10% hydrogen by volume, fuel blend with 80% natural gas &20% hydrogen by volume, fuel blend with 74% natural gas &26 % hydrogen by volume etc.

The experiments were conducted at wide opening throttle (WOT), maximum brake torque ignition timing (MBT) at engine speed of 2000 rpm. Exhaust gas analyzer was used to measure emissions.

Result & Conclusion-

- For a given A/F ratio power output & thermal efficiency decrease with increase in % of hydrogen in natural gas this is true up to when % of hydrogen is less than 20%.
- Power output & thermal efficiency increase with increase in % of hydrogen in natural gas when % of hydrogen is greater than 20%.
- Addition of hydrogen in natural gas reduces HC concentration in exhaust but NO_x concentration increases.
- For getting higher Thermal efficiency and low emissions lean burn mixture is favorable.

5 M.U. Aslam (CNG as an alternative fuel for a retrofitted gasoline vehicle)

Materials- Proton Magma Test engine with bi fueling injection system, Gasoline & CNG were used as fuel.

Property	Gasoline	CNG
Motor octane number	80-90	120
Molar Mass	110 kg/mol	16.04 kg/mol
% Wt. of carbon by mass	87	75
A/F ratio	14.6	16.79
LHV	43.6 MJ/kg	47.377 MJ/kg
Spontaneous ignition temp	480°C -550 °C	645 °C
Stoichiometric mixture density	1.38 kg/m^3	1.24 kg/m^3

Engine Specifications-

Particulars	Description
Engine Type	Proton Magma 12 valve retrofitted engine
Bore diameter	75.5 mm
Stroke length	82 mm
Compression ratio	9.2:1
Net Output	64/6000 (kW/rpm)
Net Torque	122/3500 (Nm/rpm)
Carburetor	Down-draft 2 Barrel

Experimental Procedure-

CNG & Gasoline were used as fuels and their consumptions were measured. Controlling system was used for monitoring operations. BMEP, BSFC, brake specific energy consumption (BSEC) and fuel conversion efficiency (FCE) was calculated. Exhaust emissions were measured using gas analyzer. Retrofitting is one due to different characteristics of CNG and to implement CNG in gasoline engine.

On the basis of various tests analysis was done.

Result & Conclusion-

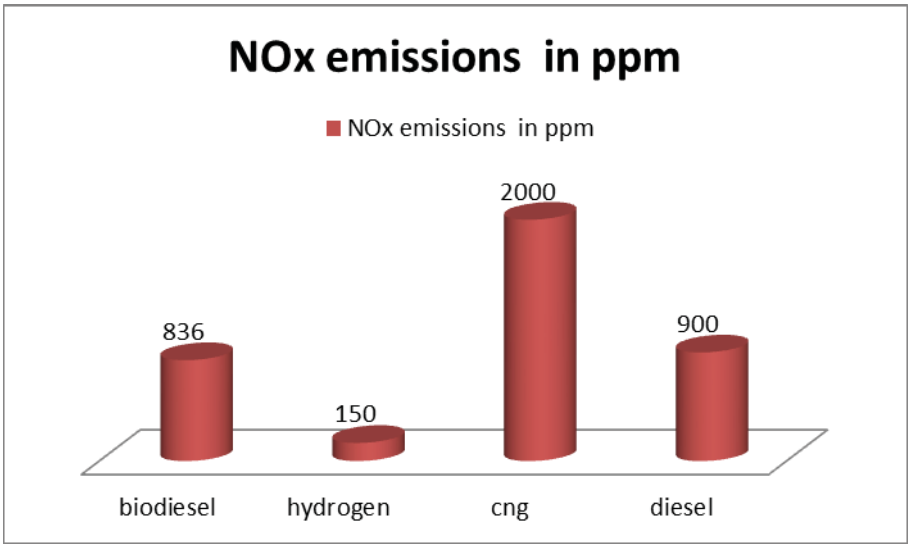
- Retrofitted CNG engine 16% less BMEP and BSFC is also less as compared to gasoline engine.
- CO CO_2 & HC emissions are reduced but NO_x emission of CNG increases as compared to gasoline.
- But there is a need to reduce Wt. of CNG tank for better performance.
- Thus Retrofitted CNG fuelled engine can be used in practice considering above conclusions.

III. CONCLUSION

The comparative study was made by studying various parameters that affect engine fuel and conclusions were plotted based on those parameters.

Blended biodiesel showed better characteristics than pure biodiesel. Brake thermal efficiency increases for pure biodiesel. Clean exhaust is obtained as compared to diesel. Hydrogen can also be used as fuel. Very clean exhaust is obtained as compared to other fuels. Power output is high at low speeds. Hydrogen & Natural gas mixture can also be used as fuel. But lean mixture is needed for low NO_x emissions. CNG can also be used as fuel certain modification in engine is needed. NO_x emissions is very high in case of CNG.

The pie chart shows NO_x emissions comparison with various fuels.



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