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Combustion and Emission in DI ESEL Engine when Supplied by Hydrogen Along with Water

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Abstract—*Hydrogen is being considered as a primary automotive fuel and as a replacement for conventional fuels. Some of the desirable properties, like high flame velocity, high calorific value motivate to use hydrogen fuel in a dual fuel mode in diesel engine. In this experiment the hydrogen was inducted in the inlet manifold with intake air. The experiments were conducted on a four stroke, single cylinder, water cooled, direct injection (DI), diesel engine at a speed of 1500 rpm. Hydrogen was stored in a high pressure cylinder and supplied to inlet manifold through water and air based flame arrestor. The pressure regulator was used to reduce the cylinder pressure from 140 bar to 2 bar. The hydrogen was inducted with various volume flow rates namely 4lpm, 6lpm and 8lpm respectively by digital volume flow meter. The engine performance, emission and combustion parameters were analyzed at various flow rates of hydrogen and compared with diesel fuel operation. This Paper will help the Automobile manufacturers to analyse the characteristics of hydrogen supplied diesel engine for the generation of effective technology in the future.*

Keywords*: Diesel engine, Hydrogen and Water, Combustion, Emission, Brake thermal efficiency.*

1. INTRODUCTION

In the modern and fast moving world, petroleum based fuels have become important for a century development. Products derived from crude oil continued to be the major and critical source of energy for fuelling vehicles all over the world. However, petroleum reserves are limited and are non-renewable. During the last decade, the use of alternative fuel in diesel engines has received renewed attention. The uncertainty of petroleum-based fuel availability has created a need for alternative fuels . At the current and projected rate of consumption of crude, it is estimated that these reserves will be badly depleted in due course and it may become impossible to meet the requirements. Diesel engine is the most efficient type of internal combustion engines. In past few decades research efforts have been focused largely on better engine design from the perspective of reducing pollutants emission without sacrificing performance and fuel economy. In recent years, an emphasis on reducing pollutant emissions from petroleum-based engines has motivated the development and testing of several alternative fuels. The main pollutants from diesel engines are NOX (NO—nitric oxide and NO2—nitrogen dioxide), particulate matter and smoke (visible product of combustion) . Various fuels have been considered as substitutes for hydrocarbon-based fuel. Alternative fuels that aspire to replace petroleum-based fuels include alcohols, liquefied petroleum gas (LPG), compressed natural gas (CNG), hydrogen, vegetable oils, bio gas, producer gas and liquefied natural gas (LNG). Of these, hydrogen is a long-term renewable and less-polluting fuel. In addition, hydrogen is non-toxic, odorless and results in complete combustion . Hydrogen can be used as a fuel in internal combustion engines either pure or blended with other hydrocarbon fuels. Due to these characteristics, researchers are focusing attention on hydrogen as an alternative fuel in internal combustion engines (ICEs) and in the development of fuel cell powered vehicles and hybrid electric vehicles .

2. PRODUCTION OF HYDROGEN

Hydrogen is only one of many possible alternative fuels that can be derived from natural resources such as coal, oil shale and uranium (or) from renewable resources. H2 can be commercially produced from electrolysis of water and also by coal gasification. Several other methods such as thermo chemical decomposition of water and solar photo electrolysis are available, but presently used at the laboratory level rather than for commercial use. The H2 fueled vehicles that could be built with current technology are not competitive with synthetic gasoline or methanol vehicles on the basis of fuel consumption or fuel cost. However, with the development of practical and highly efficient end-use converters of H2 such as fuel cells, there will be a dramatic reduction in cost and improvement in efficiency of H2 production, safe and convenient on board storage.

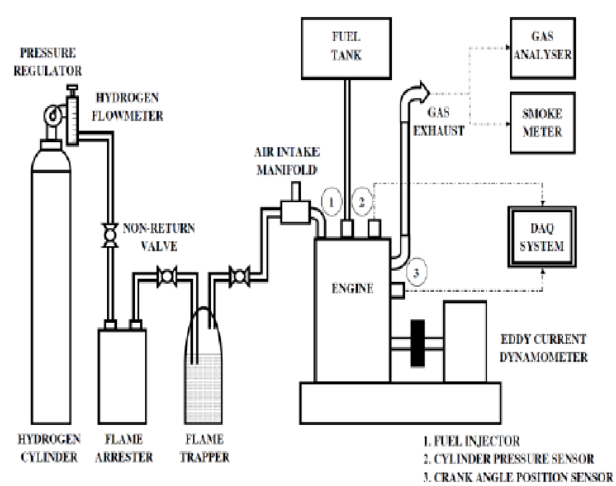
3. COMBUSTION PROPERTIES OF HYDROGEN

Hydrogen on burning produces only water. It is non-toxic, non-odorant and also results in complete combustion. Hydrogen has a high self-ignition temperature (858ºK); therefore it is difficult to ignite hydrogen with help of only compression. Due to this property, hydrogen cannot be used in a diesel engine system without an ignition source. So to start combustion some ignition source is required during the compression stroke. Before TDC a small charge of diesel fuel is injected through the conventional injection system which acts as a source of ignition. Combustion of hydrogen is fundamentally different from the combustion of hydrocarbon fuel. Hydrogen has wider flammability limits of 4–75% by volume in air compared to diesel fuel which is 0.7–5% by volume. The burning velocity is so high that very rapid combustion can be achieved. The limit of flammability of hydrogen varies from an equivalence ratio of 0.1 to 7.1. Hydrogen at Ordinary temperature and pressure is a light Gas with a density of only 1/14th that of air and 1/9th that of natural gas. By cooling to the extreme temp of 253 degrees at atmospheric pressure, the gas is condensed to a liquid with a specific gravity of 0.07. The standard heating value of Hydrogen gas is 12.1 MJ/Cum compared with the average of 38.3 MJ/Cu m for natural gas.

PROPERTIES	Hydrogen H_2
Auto Ignition Temperature (K)	858
Minimum Ignition Energy (MJ)	0.02
Flammability Limits (Volume % In Air)	4-75
Stoichiometric Mixture (Volume % In Air)	29.53
Molecular Weight (G)	2.016
Density (Kg/cm^3)	0.0838
Mass Ratio (Kg of Air/Kg of fuel)	34.4
Flame Velocity (Cm/s)	270
Specific Gravity	0.091
Adiabatic Flame Temp. (K)	2318
Quenching Gap (CM)	0.064
Heat Of Combustion (Kj/kg)	120000
Octane Number	130
Cetane Number	---
Boiling Point (K)	20.27

(1)

3.1 Experimental Setup and Procedure



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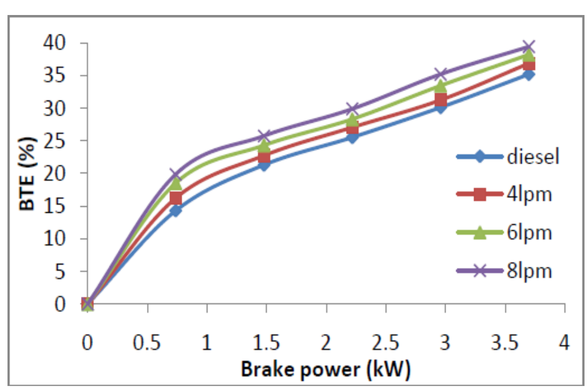
A crank angle encoder was fitted to the crank shaft to measure the crank angle. The cylinder pressure was measured by a piezoelectric pressure transducer (Make: Kistler, Type 6056A) mounted on the cylinder head. The pressure signal was sent to data acquisition system and combustion data like cylinder pressure and heat release rate (HRR) were obtained. The oxides of nitrogen (NOx), carbon monoxide (CO) and hydrocarbon (HC) emissions were measured with non dispersive infrared analyzers (NDIR) (Make: HORIBA-Japan). The gas analyzers were calibrated with standard gases before test. Initially, the engine was operated with neat diesel fuel to obtain reference data. Further, the engine was tested with dual fuel mode like addition of hydrogen with inlet air in addition to pilot diesel injection. The hydrogen gas was inducted in the inlet manifold in different flow rate namely 4lpm, 6lpm and 8lpm respectively. The hydrogen flow line consists of hydrogen cylinder, pressure regulator, flame arrester, flow meter and flow control valve shown in figure.1. The pressure of hydrogen stored in a high-pressure storage tank was reduced from 250 bar to a pressure 2 bar using a pressure regulator. Hydrogen was then passed through a flame arrestor and flame trap which arrest any backfire of the engine. It also acts as a non return valve. Then the hydrogen is passed through the digital gas flow meter, of range 0–10lpm. The combustion, performance and emission characteristics were evaluated for different hydrogen flow rates and compared with neat diesel fuel operation.

4. PERFORMANCE ANALYSIS

(Brake thermal efficiency)

Fig. 3 shows the variation in brake thermal efficiency with brake power for different flow rates of hydrogen. The 8lpm hydrogen addition gives the highest brake thermal efficiency (39.42%) compared to diesel (35.21%) at full load. The brake thermal efficiency increases with higher hydrogen enrichment. The increase in brake thermal efficiency is due to hydrogen's higher calorific value and better mixing with air in addition to its faster burning rate characteristics . It was observed that the hydrogen addition with inlet air showed the improved performance compared to normal neat diesel operation.



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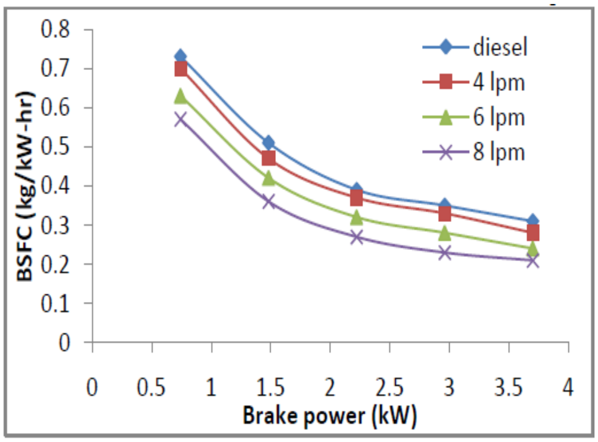
5. BRAKE SPECIFIC FUEL CONSUMPTION

Fig. 4 shows the variation of brake specific fuel consumption (BSFC) with brake power for different flow rates of hydrogen. The BSFC decreases with an increase in hydrogen addition rate with air. The lowest BSFC of 0.21kJ/kW-hr is obtained for 8lpm hydrogen enrichment at 3.7 kW compared to diesel of 0.31kJ/kW-hr. This is due to the premixing of hydrogen fuel with air due to its high diffusivity and uniform mixing with air resulting in improved combustion. The percentage of reduction of BSFC was observed 32% at full load between diesel and 8lpm hydrogen flow rate.



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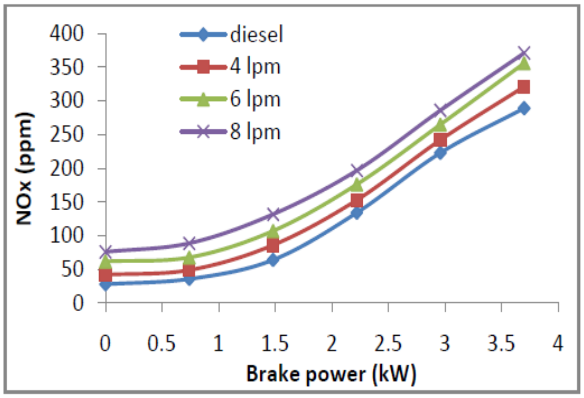
6. EMISSION PARAMETERS

(NOx Emission)

Fig. 5 shows the variation of nitrogen oxides emissions with load. NOX forms at peak combustion temperature and higher oxygen concentration . NOX formation is higher with 8lpm compared to neat diesel and other flow rates of hydrogen. As the hydrogen percentage increases, the flame speed and hence combustion efficiency increased. The percentage of increase of NOX is 25% at full load compared neat diesel.



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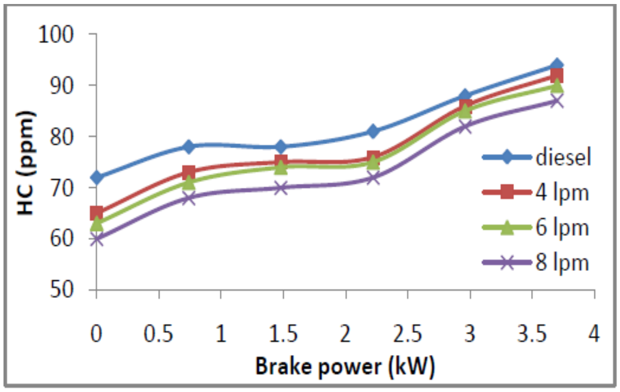
7. HYDROCARBON EMISSION

Unburned hydrocarbon decreases significantly because hydrogen fuel does not contain carbon. The variation of HC emissions with Brake power for different values of hydrogen enrichment is shown in fig 6. It is observed that the HC emission values of 4lpm, 6lpm and 8lpm hydrogen flow rate with diesel fuel operation are 90ppm, 92ppm and 87ppm respectively at full load. The lowest HC emission obtained was 87ppm with 8lpm hydrogen flow rate compared to 94ppm for diesel. The reduction in HC is due to the higher burning velocity of hydrogen, that enhances the diesel burning. The absence of carbon in hydrogen fuel also reduces the HC emissions to a greater extent. There are similar results reported in previous in previous studies.



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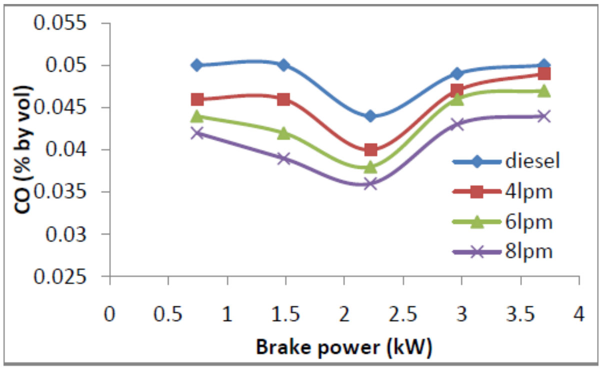
8. CARBON MONOXIDE EMISSION

The variation of carbon monoxide with engine brake power and different proportion of hydrogen enrichment is shown fig 8.The lowest CO emission was obtained as 0.044% with 8lpm when compared to 0.05% for diesel. With 8lpm the CO emission is lower than other hydrogen flow rates and neat diesel operation. The reduction CO in8lpm hydrogen-operated dual fuel engine is due to the absence of carbon in hydrogen fuel.



(7)

At no load since the engine is operated at lean equivalence ratio, a reduction in CO is observed for hydrogen dual fuel operation. But the oxygen concentration reduces significantly and in addition due to lesser reaction time it results in a significant increase in CO formation rate, that makes the overall CO concentration to increase at full load compared to diesel.

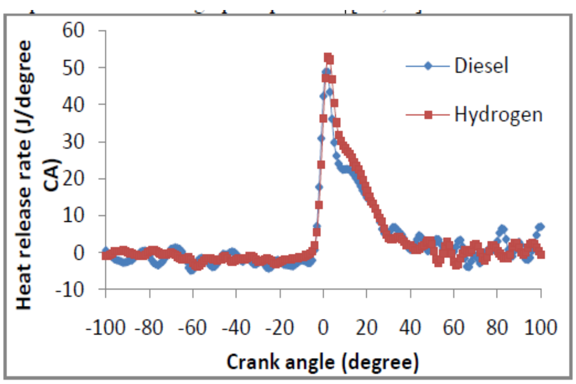
9. COMBUSTION ANALYSIS

(Cylinder pressure)

It is observed that hydrogen (8 lpm) and diesel fuel mode gives a higher peak pressure compared to diesel fuel operation at full load. With diesel, the peak pressure is 66.60 bar and with hydrogen 68.58bar peak pressure. The peak pressure for hydrogen occurs 5ºCA later than that of diesel. The pressure rise is always lower in the case of diesel operation due to its slower burning characteristics .

10. HEAT RELEASE RATE

Fig. 8 depicts the variation of heat release rate for hydrogen diesel combustion with 8lpm hydrogen enrichment at full load. It is evident that heat release for hydrogen is more rapid than for diesel. The ignition of hydrogen with 8lpm hydrogen enrichment operation takes place only after injection of diesel at 23º BTDC. It can also be observed that the highest heat release rate is 52.79 J/deg CA for 8lpm hydrogen enrichment compared to neat diesel value of 48.84 J/deg CA. This is due to the instantaneous combustion (constant volume) that takes place with hydrogen fuel. The premixed fuel burns rapidly and releases an enormous amount of heat followed by the controlled heat release. The HRR during the premixed combustion is responsible for the high peak pressure.



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11. CONCLUSIONS

Based on the experiments conducted on a hydrogen-enriched air-inducted diesel engine system, the following conclusions are drawn:

- The Brake thermal efficiency of the hydrogen with diesel fuel operation was quite higher than the diesel fuel operation over the entire brake power range. In 8lpm flow rate of hydrogen brake thermal efficiency is increased due to addition of hydrogen fuel.
- Brake Specific fuel consumption decreases with increase in hydrogen percentage over the entire range of operation.
- NOx concentration increases with higher enrichment of hydrogen (8lpm) compared to lower hydrogen enrichment and diesel.
- The Carbon monoxide emission decreased at part load and increased in full load condition. The lowest CO emission was obtained 0.044 vol. % with 8lpm hydrogen addition, compared to 0.05% for diesel.
- The HC emission for all additional hydrogen rates decreased averagely compared to diesel at full load, respectively. The lowest HC emission was obtained 87ppm with 8lpm addition hydrogen with diesel , compared to 94ppm for neat diesel.
- The Exhaust gas temperature increased for all additional hydrogen flow rates averagely compared to diesel at full load, respectively.
- The Cylinder pressure increased for 8lpm hydrogen flow rates compared to neat diesel at full load, respectively.
- HRR are higher for 8lpm hydrogen flow rates compared to neat diesel fuel. The HRR for 8lpm hydrogen flow rate is 52.79 J/deg and 48.84 J/deg CA for neat diesel fuel at full load. On the whole it was concluded that hydrogen-enriched diesel engines perform well and emit less pollution compared to neat diesel fuel. Hence, hydrogen enrichment in a CI engine can be regarded as an eco-friendly alternative fuel to sole diesel.

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