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# A REVIEW OF HYDROGEN COMBUSTION TECHNOLOGY APPLIED TO DI DIESEL ENGINES

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**Abstract**— The restoration of energy and ecological effect of fossil fuels are hopful interst in the study of alternative fuels for internal combustion (IC) engines. The scope of hydrogen fuel in cupious amount and the near zero pollutants in its combustion are making hydrogen an attractive option. However, strange properties of hydrogen, high flame speed, high calorific value and low density.In this study, a diesel engine is operated using hydrogen diesel dual fuel, where hydrogen is introduced into the intake manifold using an LPG-CNG kit and pilot diesel is injected using diesel injectors. The performance of engine increased when compared with conventaional diesel engine with increased break thermal efficiency and reduced emissions of carbon monoxide (CO), unburn hydrocarbons (HC) and nitrogen oxides (Nox). In this review focused on injection timings, injection duriation, performance and emission charecterstics of hydrogen combustion.

**Index Terms** Hydrogen combustion, Injection timing, emissions of ehgaust, mass fraction of air burn, net heat released rate.

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## 1 INTRODUCTION

Concern over the human health, environmental effect, availability, and cost of fossil fuels are motivating the researchers to investigation of alternarive fuels for automobile industry. Among the various possible alternative fuels, hydrogen is found to be most promossing due to its clean burning and better combustion properties.

There are several reasons for applying hydrogen as an additional fuel to accompany diesel fuel in the internal combustion (IC) compression ignition (CI) engine.Primary; it increases the H/C ratio of the entire fuel. Secondly, injecting small amounts of hydrogen to a diesel engine could decrease heterogeneity of a diesel fuel spray due to the high diffusivity of hydrogen which makes the combustible mixture better premixed with air and more uniform. It could also reduce the combustion duration due to hydrogen's high speed of flame propagation in relation to other fuels [1-2].

There have been various techniques used to decrease emissions. Diesel Particulate Filters (DPF) and Selective Catalytic Reduction (SCR) were used reduce PM and NOx emissions, respectively. These types of techniquics are used precious and expensive metals as catalysts and also devices are difficult in retrofitting to the engines of vehicles. Accordingly, alternative fuels are endorsed and developed as an alternative to traditional fuels to achieve thses goals. At this end, hydrogen is considered to be the best additive candidate to be blended into diesel in order to satisfy the characteristics which are required by the engine [3-4].

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Normally, the combustible mixture offers increased homogeneity and better circumstances for the total combustion process. More over, faster combustion approximates constant volume leading to an increase in the efficiency of the engine [5]. Hydrogen is one of the most promising renewable fuels because it can available naturally on the earth and also generated from resources like fossil fuels and biomass [6]. Due to safety reasons, take an extra care necessesitates using Internal Combustion engines. In addition, the hydrogen injection technique also also plays a significant role in preventing undesired explosions. Apart from direct injection is regarded as a preferred technique, compared to port injection, in ordered to avoid the backfire effect. Backfire is defined as a combustion which occurs during the intake stroke as a result of hot spots, and also happens in the intake manifolds. For safety reasons, it is crucial to prevent any unwatnted combustion behavior [7-8].

Natural gas and bio derived gas research was done in the dual fuel engine by Sahoo et al [9]. Hairuddin et al. accomplished a study on hydrogen and natural gas in diesel homogeneous charge compression iginition engine [7].

## 2 MATERIALA AND METHODS

2.1. Production of Hydrogen

Hydrogen (H2) is only one of the most promising alternative fuels that can be derived from natural resourses such as coal, oilshale and uranium (or) renewable sources [6].Commercially H2 can be produced electrolysis of water and and also coal gasification. Some of other processes such as thermo chemical decomposition of water and solar photo electrolysis are available, but currently used at laboratory level rather than for commercial use. The H2 fueled vehicles that could be built with current technology are not with syntheticgasoline or methanol vehicles on thebasis of fuel consumption or fuel cost. However, with the development of practical and highly efficient end use converters such as fuel cells, there will be a dramatic reduction in cost nad improvement in efficiency of H2 Production, safe and convenient on board storage [10].

### 2.2 Combustion and Properties of Hydrogen.

Hydrogen has a high self-ignition temperature (858°K); therefore it is very intricacy to ignite hydrogen with the 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 vitally different from the combustion of hydrocarbon fuel. Hydrogen has wider flammability restrictions 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. The Flame Speed of Hydrogen burning in the air is such greater than the natural gas, and the energy required to initiate the combustion is less. Mixture of hydrogen and air or combustible over an exceptionally wide range of compositions the flammability limits at ordinary temperatures extend from 4% to 74% by volume of hydrogen in air[10-13].

For complete combustion of hydrogen fuel the sufficient quantity of oxidization is needed. If oxidizer quantity is more than stoichiometry then the mixture is said to be lean, if it less than the stoichiometry oxidizer then the mixture is said to be rich. For complete combustion the air–fuel ratio is determined by writing simple atomic balances. Assuming 100 mol of air contain 21 mol of O2 and 79 mol of N2. 1 mol of O2 + (79/21 = 3.76) mole of N2 i.e. 1 + 3.76 = 4.76 mol of air is required for complete combustion where N2 being inert gas which does not take part in the reaction.

$$Cm + Hn + m\,[m + (n/4) + (n/4)]\,(O2 + 3.76N2)$$

$$\longrightarrow [(n/2) + (n/2)]\,H2O + mCO2 + [m + (n/4)3.76N2$$

In both reactions, the total masses of the reactant and product have remained same, which is the confirmation of the principle of conservation of mass. In this chemical reaction, the number of moles remains constant. Combustion of fuel species takes place in the presence of oxygen (air), CO2 and N2. But nitrogen being inert does not take part in the reaction [1]. The table.1 gives the various properties of hydrogen at 25°C 1 atm [10].

**Table-1 Properties of Hydrogen@ 25°c and 1 atm**

| 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 |

## 3 RESULTS AND DISCUSSIONS

Syed Azam Pasha Quadri et al.[1] conducted an experiment on Kirloskar AV-1, single cylinder direct injection, water cooled diesel engine with a 3 holes injector each with nozzle diameter of 0.15mm. The engine is coupled to an Eddy current dynamometer and evaluated brake thermal efficiency and exhaust emissions was calculated for various injection operating pressures from 200 to 240 bar at full load condition with with different percentages of hydrogen substances as shown below Fig.1, 2, 3 and 4.



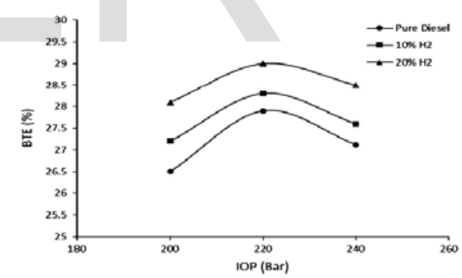


Fig.1. Effect of injection operating pressure on brake thermal efficiency.

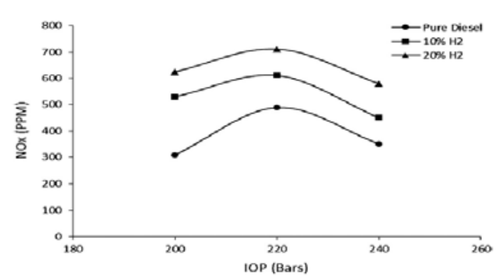


Fig.2. Effect of injection operating pressure on NOx emissions.

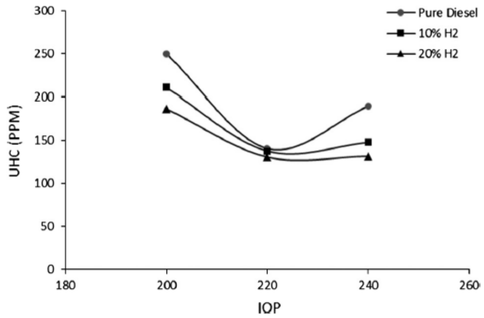


Fig.3. Effect of injection operating pressure on unburn hydrocarbons emissions.

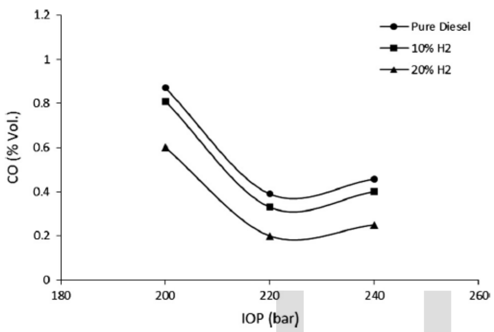


Fig.4. Effect of injection operating pressure on carbon monoxide emissions.

Madhujit Deb et al [11]. were carried out with hydrogen and diesel in dual fuel operation at constan engine speed. In that hydrogen as the primary fuel, diesel as pilot fuel and evaluated performance and emission characteristics, cylinder pressure and heat release rate shown in below Fig. 5, 6, 7, 8, and 9. During the experimentation, the hydrogen energy content of the total fuel did not surpass 42% to avoid knocking since the knocking problem was observed during experimental studies with higher hydrogen ratio values.

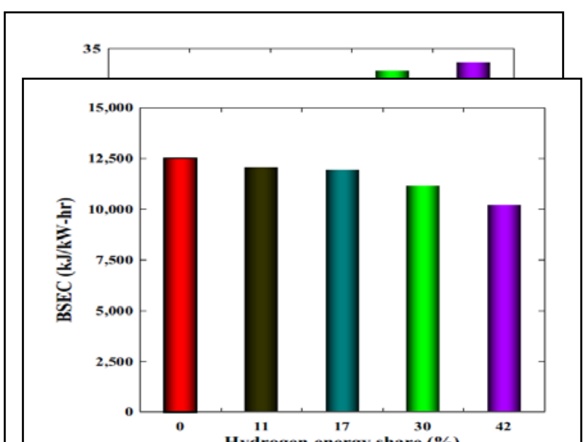


Fig.6. Brake specific energy consumption (BSEC) v/s hydrogen energy share (%).

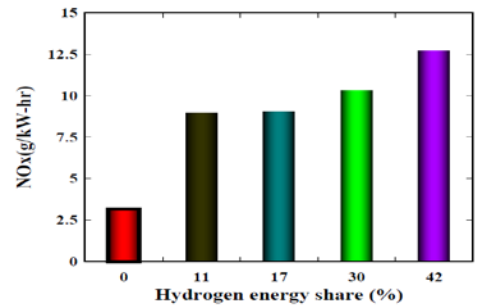


Fig.7. NOx emission v/s hydrogen energy share (%)

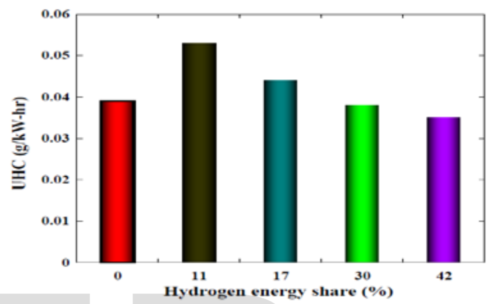


Fig.8.Un-burn hydro carbon (UBH) emission v/s with hydrogen energy share (%).

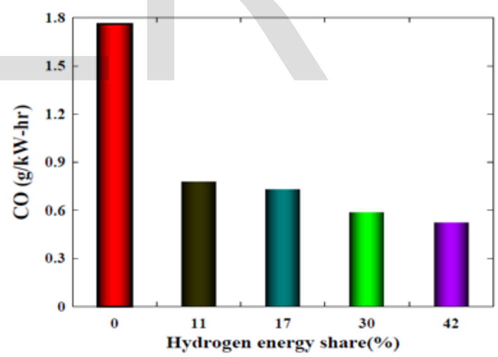


Fig.9. Carbon mono-oxide (CO) v/s hydrogen energy share (%)

N.Saravanan and G.Nagarajan [12] used hydrogen air-gas mixture in dual fuel mode by adopting carburetion, timed out and manifold injection techniques in compression ignition engine. The combustion, performance and emission characteristics compared with baseline diesel operation are presented. The test results are evaluated without SCR and with SCR converter technique at different engine load. Among the injection techniques and carburetion, port fuel injection shows an improvement in performance and combustion wit a reduction in emissions comparaed to others. Hence SCR technique was adopted with port fuel injection system for NOx reduction and evaluated performance and emission characteristics shown in given Fig. 10, 11, 12, 13, and14.

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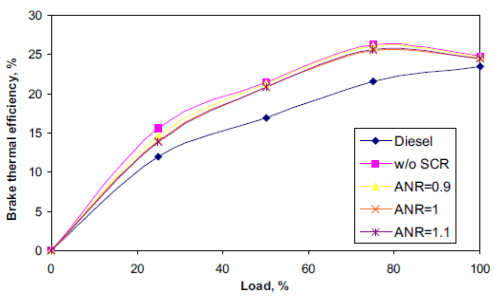

Fig.10. Variation of brake thermal efficiency with load

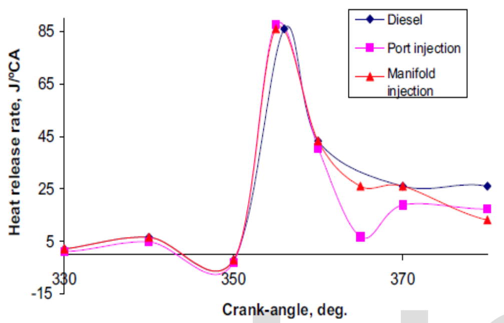

Fig.14. Heat release rate at full load

Probir Kumar Bose et al. [14] was operated a single cylinder CI engine using hydrogen-diesel blend with exhaust gas recurculation. The experiment was carried out keeping hydrogen flow constant at 0.15 kg/h in absence of EGR, with 10% EGR and 20% cooled EGR and also performance and emission characteristics was measured shown in Fig. 15, 16, 17, 18, 19, 20 and21.

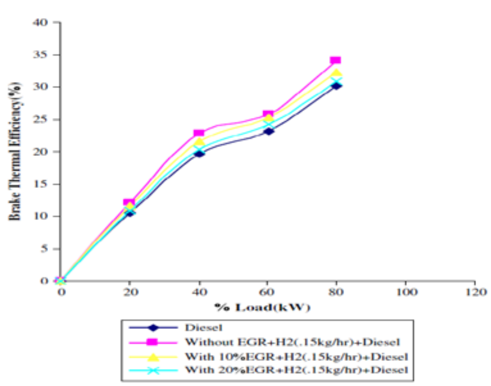

Fig.15. Brake thermal efficiency v/s Load

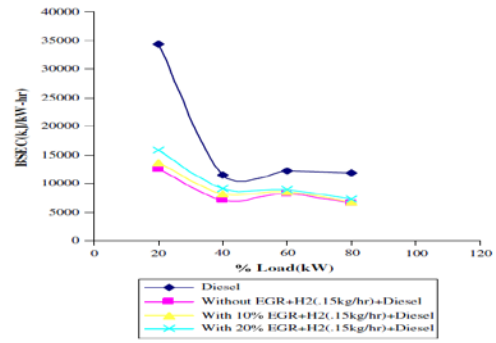

Fig.16. Brake specific energy consumption v/s load

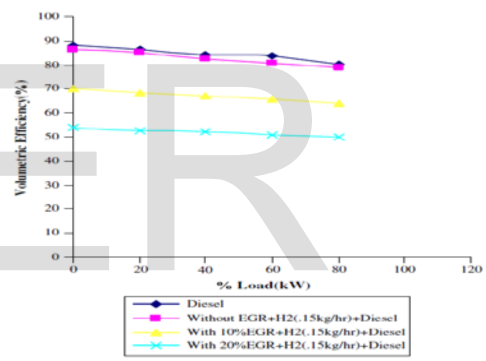

Fig.17 Volumetric efficiency v/s load

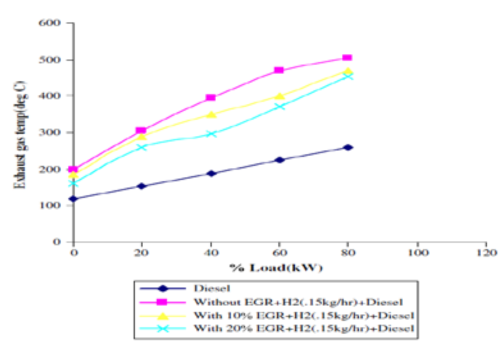

Fig.18 Exhaust gas temperature v/s load.

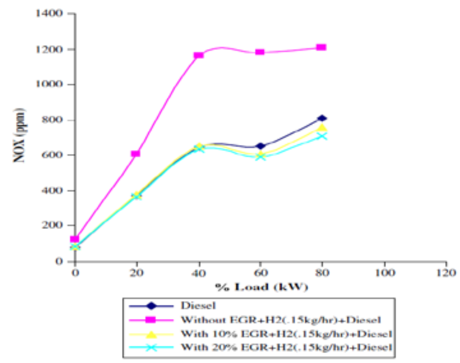


Fig.19. NOx v/s load

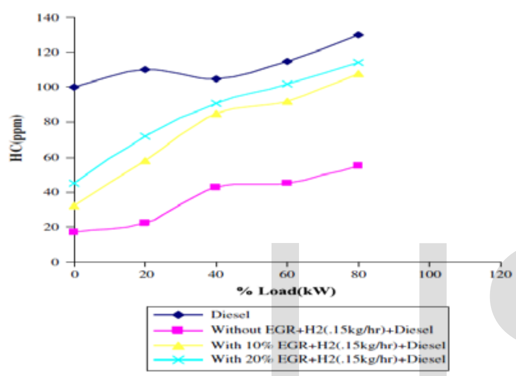


Fig.20 Un-burn hydro carbon v/s load

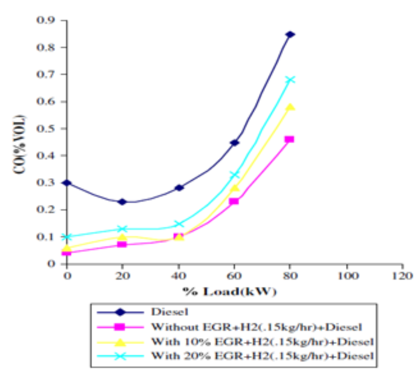


Fig.21 Carbon mono-oxide (CO) v/s load

EGR technique is useful in reduction NOx concentration. At 80% load NOx value for hydrogen enrichment without EGR is 1200ppm whereas with 20% EGR nox value is 710 ppm. The reduction in NOx is due to the reduction in peak combustion temperature because of presence of inert gas in EGR.

## 4 Conclusion

Based on the review paper fallowing conclusions are drawn:

- In the above study majority of authors have reported that BTE and brake power output are increased with the addition of hydrogen, because addition of hydrogen into diesel reduces the duriation of combustion and increases the cylinder pressure and heat release caused by increasing the velocity of the flame of the hydrogen, leading to improvement in engine performance.
- The most of the studies have measured that SEC is also affected with the increasing hydrogen. At the maximum load SEC is decreased when increasing the portion of hydrogen, but it is incrsaed gradually when the load is reduced.
- When adding hydrogen to diesel, its effect on BMEP depends on the zone of mixture. If the mixture is below stiochiometric, the BMEP reduces with the raising proportion of hydrogen, while it is increased with a lean mixture zone, as a result of the presence of oxygen.
- HC, CO and CO2 are decreased with the addition of hydrogen. Since hydrogen doesnot have carbon.
- There is another important emission from the hydrogen-diesel engine which is NOx. The NOx increment is due to the high temperature and pressure inside the cylinder, both produced by the hydrogen. However, this increase in NOx can be controlled by numerious injections, exhaust gas recurculation (EGR) or water injection as well as exhaust after ttreatment. In general, the hydrogen is recomonded to enrich the diesel but it should also take into account its harm when using it in high percentage.

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