# PERFORMANCE AND EMISSION CHARACTERISTICS OF DI DIESEL ENGINE USING HYDROGEN AND DIESEL- ETHANOL BLEND

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## Abstract

Environmental issue is a principal driving force which has led to a considerable effort to develop and introduce alternative transportation fuels. Hydrogen is considered to be low polluting fuel and is the most promising among alternate fuels. Its clean burning characteristics and better performance attract more interest compared to other fuels. A major problem with hydrogen fuel is the increased $NO_x$ emission. To reduce $NO_x$ emission Diesel-Ethanol blends were used at various proportions. Diesel-Ethanol blends up to 20% can very well be used in present day constant speed C.I engines without any modification. The present work deals with the experimental study of performance and emission characteristics of DI diesel engine using Hydrogen and Diesel-Ethanol blend. Hydrogen was injected by a port fuelled injection (PFI) system controlled by an electronic control unit. Diesel-Ethanol blend fuel was injected in to the cylinder at the end of the compression stroke by a diesel injector under dual fuel mode. Hydrogen and Diesel-Ethanol blend was used to improve the performance and lower pollutant emissions. The experiment was conducted using Diesel-Ethanol fuel at different blend ratios with hydrogen in a single cylinder DI diesel engine and results were compared with the base Diesel. Improved in thermal efficiency and a reduction in CO, $NO_X$ and smoke were observed with hydrogen and Diesel-Ethanol blends.

***Keywords:*** Emission Characteristics, DI Diesel Engine, Hydrogen, Diesel – Ethonal Blend.

## 1. Introduction

Direct injection diesel engines are fuel-efficient driving power plants in automotive applications, because of their superior fuel economy relative to spark ignition and indirect injection engines of comparable capacity. The problem of environmental pollution in urban area is mainly caused by $NO_x$, particulates and smoke emission which are emitted from the diesel engine. Also, stringent emission regulations and foreseeable future depletion of crude reserves drives us towards the lookout for new technologies to minimize pollutant emission and improve fuel economy.

Many investigations of improvement of combustion characteristics and exhaust gas emission of diesel engine, such as high pressure fuel injection, fuel modifications, alcohol fuels, Exhaust Gas Recirculation (EGR) and the after treatment technology have been conducted. Among various developments to reduce emission, the application of oxygenated fuels to diesel engines is an effective way to reduce pollution without any modification of the engine. Now alternative fuel technology under evaluation includes alcohol, CNG, LPG and bio-diesel.

Ethanol blend in diesel fuel also offers greater potential for reducing emission and dependency on fossil fuel. In the past, many investigations were carried out on the use of in diesel engines. According to literature, there are mainly three methods of application. The first and the commonly used method is the direct use of pure ethanol in diesel engine. The engine needs a modification due to the differences between ethanol and diesel fuel properties. Furthermore, additives which enhance ignition should be added to ethanol so it can be compression ignited. The second option is the use of dual-fuel system. Besides the original diesel injection system, another injection system must be adopted to inject the ethanol fuel and the ethanol can be injected into the intake port or directly into the cylinder. The third option is blended fuel. In which diesel engines need little or no modification. Therefore, it's a most feasible to run blend fuel on existing engines.Al-Baghdadi. M.A.S (2001) has investigated the performance and pollutant emission of a four-stroke spark ignition engine using hydrogen–ethanol blends as fuel. . The results showed that the supplemental hydrogen in the ethanol–air mixture improves the combustion process and hence improves the combustion efficiency, expands the range of combustibility of the ethanol fuel, increases the power, reduces the s.f.c., and reduces toxic emissions. De-gang Li et al (2004) performed experiments on a water cooled single cylinder direct injection diesel engine using 0% (neat diesel fuel,)5%(E5-D),10%(E10-D),15%(E15-D),and 20%(E20-D) ethanol–diesel blended fuels. The results indicated that: the brake specific fuel consumption and brake thermal efficiency increased with the increase of ethanol contents in the blended fuel at overall operating conditions; smoke emissions decreased with ethanol-diesel blended fuel, especially with E-10 and E15.CO and $NO_x$ emissions reduced for ethanol-diesel blends, but THC increased significantly when compared to neat diesel fuel. Rakopoulos. C.D et al (2006) evaluated the effect of using blends of ethanol with conventional diesel fuel, with 5%, 10% and15% (by vol.) ethanol. The tests were conducted using each of the above fuel blends or neat diesel fuel, with the engine working at a speed of 2000 rpm and at four different loads. Saravanan et al (2008) made a combustion analysis on a DI diesel engine with hydrogen in dual fuel mode. The combustion analysis was done on a direct injection (DI) diesel engine using hydrogen with diesel and hydrogen with diethyl ether (DEE) as ignition source. Hydrogen was injected through intake port and diethyl ether was injected through intake manifold and diesel was injected directly inside the combustion chamber. Injection timings for hydrogen and DEE were optimized based on the performance, combustion and emission characteristics of the engine. The major pollutants from the diesel engines are NOx (NO-Nitric Oxide and NO2-Nitrogen dioxide) and smoke intensity (Sukjit et al., 2013; Isaac JoshuaRamesh Lalvani et al., Annamalai). In order to minimize these harmful pollutants we have to look for an alternative fuel that would not only reduce these pollutants but could prevent the emission of other pollutants like aldehydes, ketones, and SOx (Wallner et al., 2011). The proposed alternative fuel are vegetable oils, alcohols, LPG, CNG, and hydrogen. Among these, hydrogen and vegetable oils emerge as a aspiring solution to the fall of fossil fuels, which acts as a renewable, recycleable, and promising long term fuels (Parthasarathy et al., 2013). Vegetable oils can be directly used in compression ignition engines without any modification. The primary problem associated with using pure vegetable oil as a fuel in a compression ignition engine is caused by viscosity (An et al., 2012). Transesterification is one of the peculiar technique by which the viscosity of the fuel can be reduced for implementating in compression ignition engine. In this process the vegetable oil is reacted with ethanol or methanol in the presence of a catalyst (NaOH) at 80 °C to get biodiesel (Roy et al., 2011). Mohan Raj et al. Mohan and Murugumohan Kumar (2012) conducted an experiment a study on tamanu an alternative fuel for diesel engine. They have selected methyl esters of vegetable oils are like Cotton seed, Pongamia, Rice bran and tamanu are used as a fuel in CI engine. Among these, TME shows excellent properties than other fuels.

## 2. Use of Gaseous Fuel

Use of gaseous fuels in the internal combustion engine has a strong appeal from the pollution point of view, which could assist in reducing global warming. Over the past two decades, there has been a considerable effort in the world to develop and introduce alternative gaseous fuels to replace conventional fuel. Hydrogen is receiving considerable attention as an alternative source of energy to replace the rapidly depleting petroleum resources. Its clean burning characteristics provide a strong incentive to study its utilisation as a possible engine fuel. Hydrogen is expected to be one of the most prominent fuels in the near future for solving greenhouse problem.

## 3. Ethanol-Diesel Blend

Ethanol can be used as a fuel as such or blended into gasoline or diesel. Among various developments to reduce emissions, the application of oxygenated fuels to diesel engines is an effective way to reduce pollution. Such as ethanol, are renewable, most widely studied bio fuels for diesel engines and have received considerable attention in recent years.

Ethanol–diesel blend up to 20% can very well be used in present day constant speed C.I. engines without any modification. There will be no significant difference in the power produced and brake thermal efficiency of the engine. The brake specific fuel consumption will slightly increase when the higher blends of ethanol are used. Exhaust gas temperature and lubricating oil temperatures were lower for ethanol – diesel blends than straight diesel fuel. The engine could be started normally both hot and cold conditions. By 62% reduction in CO emission was possible with the use of ethanol- diesel blends as compared to diesel, the $NO_x$ emissions were also reduced by 24% when using ethanol – diesel blends.

## 4. Experimental Set-Up and Methodology

The experimental setup consists of an engine connected to an electrical dynamometer. Also a hydrogen kit is used to ensure safety. The hydrogen kit is used to arrest the flame in case of any mishaps. The engine to be used in a AV1, single cylinder, four stroke, water cooled, direct injection diesel engine developing a rated power of 3.7kW at a rated speed of 1500 rpm. The photographic view of the test engine setup is shown in Fig

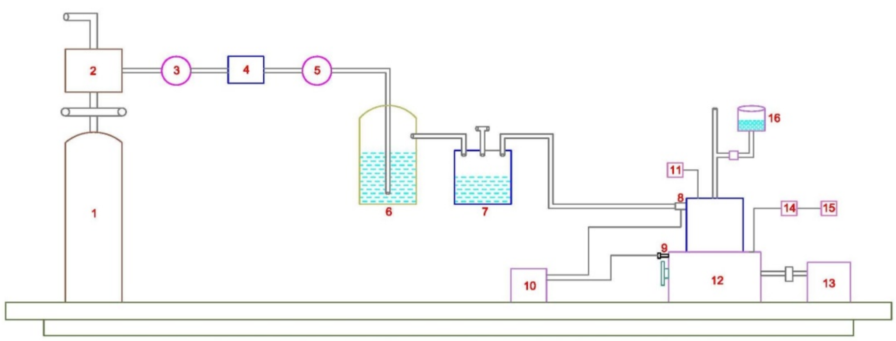


Fig 1: Schematic Diagram Of The Experimental Setup

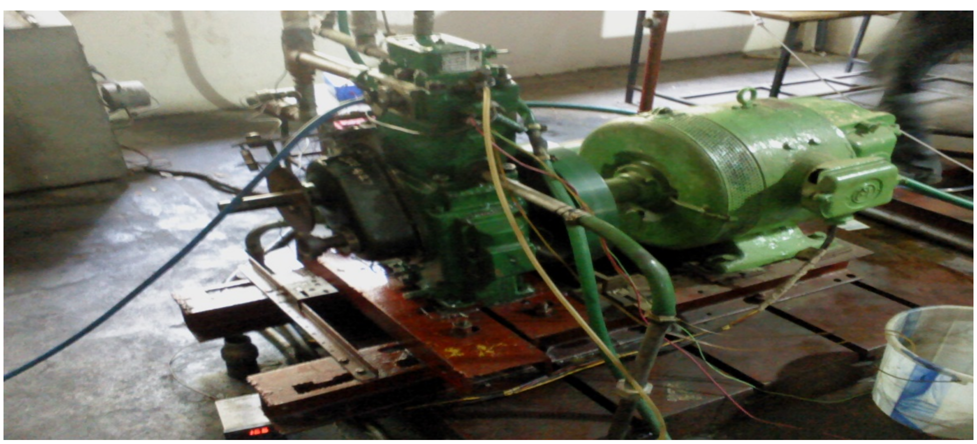

Fig 2: Photographic view of the Test Engine Setup

## 5. Experimental Procedure

Hydrogen gas stored in a high-pressure cylinder at 160 bar is reduced to a value of 1 – 2 bar by using a pressure regulator. Hydrogen is then passed through a fine control valve to adjust the flow rate of hydrogen. Subsequently hydrogen passed through a mass flow controller, which meters the flow of hydrogen in terms of Standard Litres per Minute (SLPM).

Hydrogen is then allowed to pass through flame trap, which is used to suppress the flash back if any into the intake manifold. The flame trap used here is a wet type flame trap. In general wet flashback arrestors work by bubbling the gas through a non-flammable and ideally non-gas-absorbing liquid; in this case the liquid used is water. Hydrogen is then passed through flame arrestor. It is used to suppress possible fire hazards in the system. These flame arrestors operate on the basic principle that the flame gets quenched if sufficient heat can be removed from the gas by the arrestors. It also acts a non-return valve.

Hydrogen from the cylinder after passing through the flame arrestor is inducted through the gas injector, which is fitted in the inlet port. The engine was started with diesel as the fuel. Then hydrogen was introduced in the intake port by using hydrogen gas injectors and it is brought to steady state conditions. The engine parameters were measured with different timing. At the end of the process, hydrogen flow rate was reduced to zero and the engine was made to run at steady state condition using diesel at no load condition.
To achieve constant speed of 1500 rpm at different loads the mass flow of hydrogen is varied. The emissions and performance characteristics of the above engine studied.

## 6. Results and Discussion

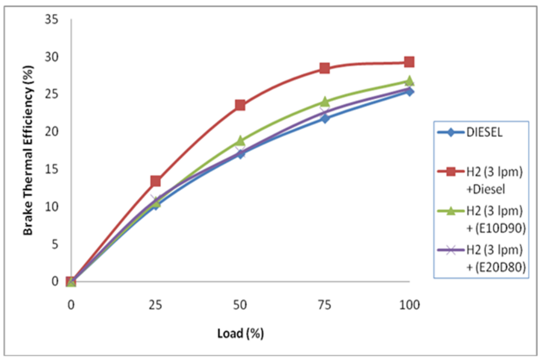


Fig 3: Variation of Brake thermal efficiency With load

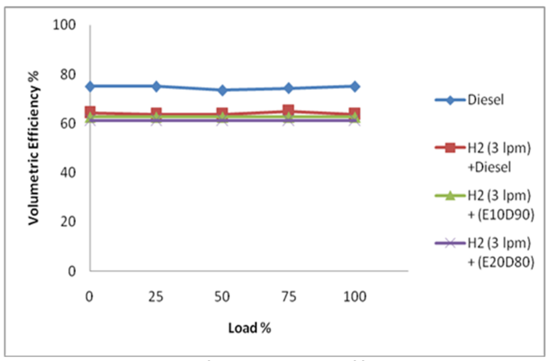


Fig 4: Variation of Volumetric efficiency with load

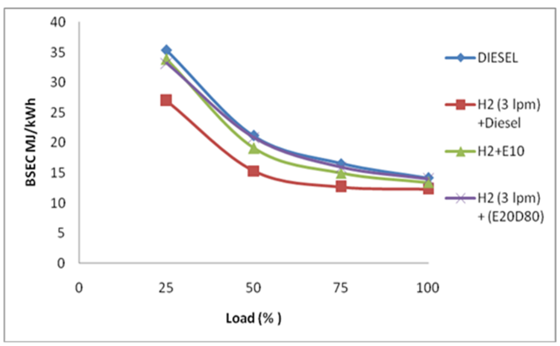


Fig 5: Variation of Brake Specific Energy Consumption With load

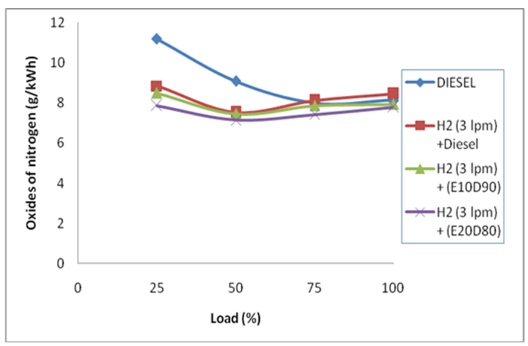


Fig 6: Variation of Nitric oxide emission with load

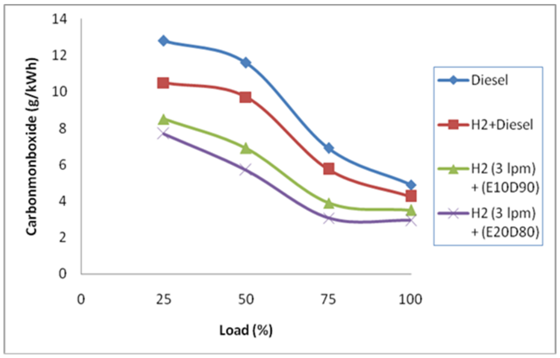


Fig 7: Variation of Carbon monooxide with load

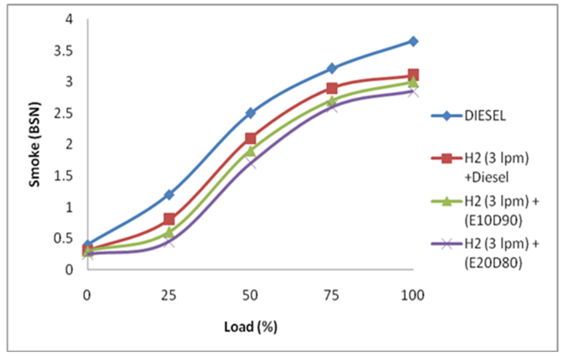


Fig 8: Variation of smoke emissions with load

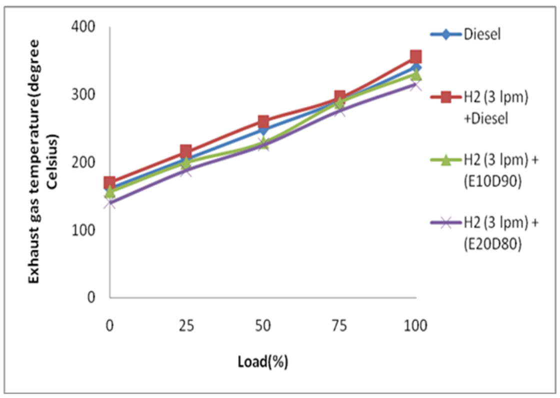


Fig 9: Variation of Exhaust gas temperature with load

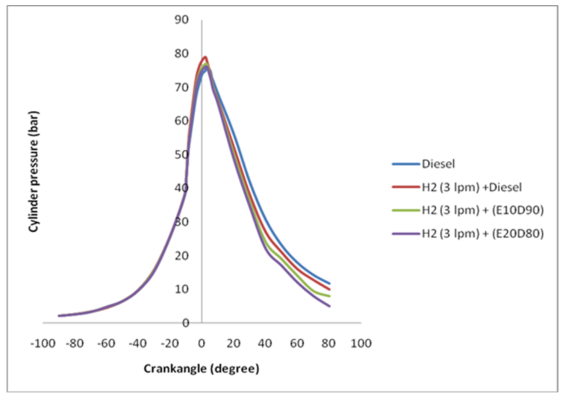


Fig 10: Variation of cylinder pressure with crank angle

### 6.1 *Variation of Brake Thermal Efficiency with Load*

In the experiment it was observed that as flow rate of hydrogen started increasing there is decrease in low rate of diesel. It indicates that hydrogen is taking part in the combustion and increase in thermal efficiency is attributed to enhanced combustion rate due to high flame velocity of hydrogen. Use of Hydrogen and Diesel-Ethanol blend had a negative effect on engine efficiency that increases with its percentage. At full load hydrogen with (10 % Ethanol and 90 % Diesel) the brake thermal efficiency was 27 %, hydrogen with (20 % Ethanol and 80 % Diesel the brake thermal efficiency was 26 %. The reduction in brake thermal efficiency Hydrogen with Ethanol-Diesel blend when compared to brake thermal efficiency of hydrogen is attributed to the low calorific value of ethanol. Also the brake thermal efficiency of Hydrogen and Diesel-Ethanol blends higher when compared to neat Diesel.

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### *6.2 Volumetric Efficiency*

Fig 4 shows the variation of volumetric efficiency with load for neat Diesel, Diesel with 3 lpm of hydrogen enrichment the same, Hydrogen with blend of 10% Ethanol and 90% Diesel, and Hydrogen with 20% Ethanol and 80% Diesel. The volumetric efficiency obtained for 3 lpm of hydrogen enrichment without blend was 63.68% compared to neat Diesel fuel of 75% at full load. The decrease in volumetric efficiency is due to the fact that hydrogen being much less dense than air displaces an appreciable amount of it while being inducted into the cylinder. When hydrogen and Diesel-Ethanol blend is used there is further decrease in volumetric efficiency. Hydrogen with blend of 10% Ethanol and 90% Diesel it was 62.56% and Hydrogen with 20% Ethanol and 80% Diesel it was 61.26% at full load. The decrease in volumetric efficiency when operated with Diesel-Ethanol blend is due to the fact that the blended fuel is less denser and hence results in the reduction of volumetric efficiency.

### *6.3 Variation of Brake Specific Energy Consumption With Load*

Fig 5 shows the variation of brake specific energy consumption with load for neat Diesel, Diesel with 3 lpm of hydrogen enrichment and the same, Hydrogen with blend of 10% Ethanol and 90% Diesel and Hydrogen with blend of 20% Ethanol and 80% Diesel. It is observed that BSEC of neat Diesel was 14.17MJ/kWh whereas BSEC with Hydrogen and Diesel was 12.31MJ/kWh, Hydrogen with blend of 10% and 90% Diesel it was 13.42MJ/kWh, and Hydrogen with blend of 20% and 80% Diesel it was 13.94MJ/kWh all these readings are at full load of rated load. The BSEC in case of hydrogen enrichment is less compared to neat diesel operation. This is due to better mixing of hydrogen with air resulting in complete combustion of fuel. The BSEC increases Hydrogen with E10D90 and Hydrogen with E20D80 due to the fact of lower calorific value of ethanol when compared to Hydrogen-diesel whereas the BSEC decreased when compared with Diesel.

Experiments were conducted to study the performance, combustion and emission Characteristics of DI diesel engine using hydrogen gas by means of port injection technique with diesel and diesel-ethanol blend as the mode of ignition. Based on the experimental study the following conclusions are drawn

The experiment shows the following findings

- The brake thermal efficiency showed an increase substantial for Hydrogen and Diesel with the supply of 3 lpm of hydrogen when compared neat Diesel. The increase was due to uniformity in mixture formation and enhanced combustion. Use of Hydrogen and Diesel-Ethanol blend had a negative effect on engine efficiency that increases with its percentage. The reduction in brake thermal efficiency with Diesel-Ethanol blend when compared with that of Hydrogen and Diesel can be attributed to the lower calorific value of ethanol. Also the brake thermal efficiency of Hydrogen with Diesel-Ethanol blends was higher when compared to neat Diesel.
- Volumetric efficiency was maximum with neat diesel operation. In case of hydrogen enrichment volumetric efficiency decreased. There was further reduction in volumetric efficiency with ethanol, being low density fuel and due to the fact that Hydrogen being much less denser.
- BSEC in case of hydrogen and diesel was less compared to that of neat Diesel operation. The reduction in BSEC was due to the higher calorific value of hydrogen and operation of hydrogen fuelled engine under lean burn engine conditions. The BSEC increased with Hydrogen and (E10D90), and Hydrogen and (E20D80) due to lower calorific value of ethanol. Also BSEC of Hydrogen and Diesel-Ethanol blends decreased when compared to neat Diesel.
- Due to better combustion hydrogen exhaust gas temperature was high in case of Hydrogen and Diesel. Exhaust gas temperature was found to be lower when ethanol added, due high latent heat of vaporisation of ethanol.
- Smoke levels showed a decreasing trend for hydrogen and diesel when compared to neat Diesel operation. The reduction in smoke was due to the absence of carbon in hydrogen structure. When hydrogen and diesel-ethanol blend was used, there was further reduction in smoke level. The carbon particles are completely burned due to the presence of enough oxygen content in ethanol and reduced the smoke level.
- The CO emission decreased for hydrogen and diesel compared to neat Diesel operation at full load. When hydrogen and diesel-ethanol blend is used the CO emission will be decreased due to the increase in oxygen concentration. Ethanol has less carbon than diesel.
- The HC emission decreased for hydrogen and diesel compared to diesel. In case of diesel-ethanol blend the HC emission increases with addition of ethanol is due to higher heat of vaporization of the ethanol blends cause slower evaporation and poorer fuel-air mixing.
- NOx emission showed an increase for hydrogen and diesel when compared to neat Diesel. For hydrogen and diesel-ethanol blend, the NOx emission is reduced due to use of diesel-ethanol blend along with

hydrogen. Decrease in NOx concentration was that ethanol having a high latent heat of vaporisation lowers the flame temperature resulting in lower combustion temperature. Lower combustion temperature results in lower NOX formation.

## 7. Conclusion

Thus the present experimental investigation on a single cylinder engine with Hydrogen and Diesel proves to be viable approach to reduce pollutant level and improved performance. It is to be noted that hydrogen combustion with diesel fuel is plagued by the formation of NOx due high flame temperature involved. NOx emission shows a steady decrease with the use of diesel-ethanol blend along with Hydrogen. Decrease in NOx concentration was due to ethanol having high latent heat of vaporization lowers the flame temperature resulting in lower combustion temperature. Lower combustion temperature results in lower NOX formation.

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