

Experimental Investigation of the Effects of Hydrogen Addition with Diesel on Performance and Emission of a Single Cylinder Diesel Engine

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Abstract-- Need of the hour in present day scenario is to cope with energy crisis and human life in India and around the globe which is associated with depletion in the percentage of petroleum products and increase in the share of pollution caused due to emissions from diesel operated engines. This work tries to address these two major concern with the use of alternative fuel for diesel engine. A lot of research is going on the use of alternative and innovative fuels in the word, among those one of the most promising alternative ought to be hydrogen for being a clean and non carbon in nature. However various ongoing researches shown hydrogen blending to be proved to show positive effect on performance and emission of a diesel engine, which has to be carried forwarded. In this work a flow rate of 4 lpm, 6 lpm and 8 lpm respectively blend of hydrogen proportion where used along which diesel at loading at a constant speed of 1500 rpm to determine various engine performance parameters such as brake thermal efficiency, brake specific fuel consumption, brake power, indicated thermal efficiency, mechanical efficiency, volumetric efficiency, torque output and power output. along with these various emission parameters such as percentage of CO, HC, NOx gas temperature with varying blend proportion are also observed and compared.

Keywords—alternate fuel, brake power, emission, exhaust gas, fuel efficiency hydrogen, pollution control.

I. INTRODUCTION

Present world is facing two major problems economically, ecologically and politically. The first one is associated with the fast depletion of fossil fuel majorly petroleum and its allies, and the other problem is degradation of human health due to harmful emission of diesel engines. With the emergence of diesel as a powerful fuel for transportation sector researches were focused on maximum use of this fuel for obtaining its use in transportation sector. With the passage of time a record and sharp depletion of diesel and its products, research focus shifted towards enhancement of performance of engine many modifications on the engine and other parts

where done to gain maximum output from this fossil fuel with increase in the usage of diesel oil there emerges the problem of harmful emission from diesel operated engines. Various organisations and institutes around the globe realised this problem and various awareness programs where being carried out for its control along with research works.

Now, the aim of researchers is to have a shift from conventional fossil fuels to alternative fuels with keeping in mind about the reduction in the harmful emission from the diesel engine. This work aims to carry forward the ongoing research works of enhancement of diesel engine performance along with reduction in emissions with the help of using a non carbon fuel i.e. Hydrogen (H₂) in varying percentage as blend with diesel fuel in a single cylinder diesel engine. A blend of Hydrogen in flow of 4lpm, 6 lpm, 8 lpm, in proportion where used along which diesel at loading and constant speed of 1500rpm to determine various engine performance parameters such as brake thermal efficiency (BTE), brake specific fuel consumption (Bsfc), brake power (BP), indicated thermal efficiency (ITE), mechanical efficiency, volumetric efficiency, torque output and power output. Along with these various emission parameters such as percentage of CO, HC, NOx gas temperature with varying blend proportion are also observed and plotted as shown in graphical forms. The present work will try to provide detail information on alternative fuels which can be used as a promising fuel for replacing diesel or at least reduce on the dependence on diesel as the lone fuel for transportation sector and heavy engine vehicles with reduction in the harmful emission emerging from the diesel engines. Steep depletion in the reserves of fossil fuel has created a need of shifting to fuels which are fossil fuel independent. This can only be achieved by innovation researches in the field of renewable sources of energy.

1.1 HYDROGEN AS AN ALTERNATE

Hydrogen is the fuel of the long run. An infatuated research worker of alternative understands the importance

of a shift to a hydrogen economy. Hydrogen is associated energy carrier that may be utilized in combustion engine or fuel cells producing nearly no green house emission on combustion generally the sole emission is vapour. Hydrogen production and storage is presently undergoing intensive analysis. Solar hydrogen system will give the suggests that of a completely emissions free technique of producing hydrogen

An alternative fuel should be technically feasible, economically viable, simply convert to a different energy kind once combusted, be safe to use, and be probably harmless to the surroundings. Hydrogen gas is that the most abundant element on earth. Though hydrogen doesn't exist freely in nature, it are often made from a variety of sources like steam reformation of natural gas, gasification of coal, and electrolysis of water. Hydrogen gas will employed in traditional gasoline-powered internal combustion engines (ICE) with negligible conversions. However, vehicles with polymer electrolyte membrane (PEM) fuel cells offer a bigger efficiency. Hydrogen gas combusts with oxygen to provide vapour. Even the production of hydrogen gas is often emissions-free with the utilization of renewable energy sources.

Table: Fuel properties of natural gas and hydrogen

Fuel properties	Natural gas	Hydrogen
Density in 1atm at 300 kg/m	0.745	0.082
Stoichiometric air to fuel ratio (vol%)	9.396	2.387
Stoichiometric air to fuel ratio (wt %)	0.062	0.029
Laminar flame speed (m/sec)	0.380	2.900
Quenching distance mm-1	1.900	0.600
Mass lower heating value MJ/kg	43.726	119.220
Volumetric heating value MJ/kg	32.970	10.220
Octane number	120.00	–
C/H ratio	0.251	0.000

II. LITERATURE REVIEW

V. Juric and D. Zupanovic stated that there is an inclination of significant growth in the use of diesel fuel from 1980s to the current decade and afterwards. There is a possibility of diesel to touch the half mark of the market share by the end of 2030.the rational for this exaggerated usage lies primarily in their higher profit because of readily availability and higher economic efficiency [1].Lee Schipper et al. In the report submitted to Asian

development bank sustainable development illustrate that the transport sector contributed twenty third of the overall greenhouse gas (CO₂) emissions within the world consistent with the most recent estimates of the International Energy Agency (IEA). Within road transport, vehicles and light-weight trucks turn out run out hour of emissions, but in low- and middle-income developing countries, freight trucks (and in some cases, even buses) consume additional fuel and emit additional greenhouse gas than the same light-duty vehicles. Transport-related greenhouse gas emissions from developing countries can contribute in increasing proportion to international greenhouse gas emissions unless mitigating measures are implemented shortly. These developments are often understood by the fact that maximum growth in greenhouse gas emissions would be in developing countries of Asia. There is now a growing international accord that future targets for greenhouse gas reductions within the post- 2012 Climate Policy Framework won't be achieved unless greenhouse gas contribution from the transport sector in developing countries is fittingly addressed [2].In the contrast to Indian states detailed estimated emission data was provided by T.V. Ramachandra and Shwetmala which provide the information that total amount of greenhouse gas emitted from transport sector in India was 258.10 Teragram Tg in a year. Among this, only the road transportation contributed more than 94 % and in the form of CO₂ and CO its 53.3%.The largest contributor state was Maharashtra constituting about 11.8%,after which follows T.N (10.8%) , Gujarat (9.6 %) , U.P (7.1 %) , Rajasthan (6.22%) and Karnataka (6.19 %).These six states constituted about 52 % of the emission on Indian road [3].Topias et al. Elaborated about the particulate materials which are very tiny particles produced due to incomplete burning in the combustion chamber. These PM are in 'trade off' to the NO_x produced because they depend on the combustion chamber temperature .These have a lot of ill effects on health ,PM are actually complex mixture of solid, fully volatile ,partially volatile, organic and inorganic compounds [4].Gurumurthy Shebbar in his paper elaborated a number of methods, techniques, modification for control and reduction of NO_x during operation of internal combustion engine [5]. These included Early In-Cylinder Injection, which can be achieved by injection of fuel, potion wise or entirely by using a separate injector or the same one during the fuel intake or during early stage of compression stroke. Modulated Kinetics ,in this the injection of fuel is done directly into combustion chamber or after the top dead centre .Wall impingement remains a problem here which can be avoided with the control of combustion phasing.According to a report by hill's group [6], if the continuous depletion of crude oil is continued, its

production is going to decline faster than we generally assume. it further states that 25 % of the world's energy proving reserves will be orders of magnitude much more costly than it was for the first 25 % part [7]. R.W Bentley talks about political and physical risk of global conventional oil supply, political risk because the addition of conventional production from all countries within the world, except the 5 main Middle-East suppliers, is close to the utmost set by physical resource limits. the physical risk is because the Middle-East countries have solely very little spare operational capability, and this may be progressively known as upon as production declines elsewhere. If demand is maintained, and if giant investments in Middle East capacity aren't created, the planet can face the prospect of oil shortages within the close to term [8]. United States of America constituting the 5.5 % of the world consumes 35% of the consumption of global energy whereas Asia, Africa and Latin America which has 70% of world population, have a consumption of the world, this can be concluded as energy consumption by one American is equal to 40 Indians and which will be equivalent to ninety Nigerians [9]. this data make a sense for emphasis to move to the alternative sources of energy by the Indian sub continent. Though steam reformation of methane is presently the most important route to hydrogen production, the emissions concerned may also be controlled way more expeditiously than our current system of transportation fuel [10]. S K Sharma et al. Discussed about the technical feasibility of hydrogen filled internal combustion engine [11]. F A de Bruijin concluded that hydrogen from wind and P V is lone option, where no electricity can be used directly; also states hydrogen does not fall under ideal storage medium of energy and it lead to significant losses of energy in transportation [12]. The government of India report on hydrogen fuel vehicle transportation emphasis on safety measures and enhancement of infrastructure in the country for further growth of use of Hydrogen as an alternative fuel for transportation sector, it also found the hydrogen fuel as cleaner of the other alternative sources of energy which can be used as fuel for transportation sector or vehicles [13]. There are good prospects to boost the combustion method among the engine cylinder through the suitable provision of chemical action surfaces. In general it's finished that hydrogen operated dual fuel engine shows associate improvement in performance and reduction in emissions except NOx which may be controlled effectively with selective chemical action reduction technique that is compatible for hydrogen-dual fuelled engines [14]. Electrolysis of distilled water can be used for the generation of hydrogen in which an electric current is supplied to closed distilled water container for its electrolysis process [15]. For a faster and effective reaction KOH powder can be added in

the kit which would act as a catalyst to enhance the rate of hydrogen production. As hydrogen is not available directly in nature as a fuel, it has to be produced by different means and processes various Hydrogen production methods were discussed by O Bicakova and P Starka [16]. Aritra chatterjee emphasised on efficient and commercially valuable and safe production, storage and distribution of hydrogen to make it a feasible fuel for transportation sector and vehicles [17]. In SI engine ignition timing plays an important role when hydrogen blending is applied to it, during combustion in SI engine with hydrogen blend brake mean effective pressure increases because of rapid combustion of hydrogen allows very little loss of heat to the surrounding, thus increasing local temperature and hence brake mean effective pressure [18]. The structure of a hydrogen fuelled engine is not much different from that of a conventional internal combustion engine but if a gasoline engine without any modification uses hydrogen as fuel some trouble such as smaller power output, abnormal combustion in the form of backfire, pre ignition, high pressure rise rate and even knock and high NOx emission would occur. So the fuel supply system of hydrogen engine and its combustion system needed suitable modification [19]. By using hydrogen in proportion to CNG [20], it is observed that an increase in proportion to brake thermal efficiency (BTE), and decrement in CO and HC with increase in hydrogen percentage and it showed the blending of hydrogen could be a lot beneficial for increasing the lean burning limit and have a trade off system between CO, HC and emission of NOx. Along with numerous experimental methods on hydrogen blending, mathematical methods are also used for studies. Samir M Abdul Hakeem and Haroun A.K. Shahad worked on numerical approach [21] to have a better understanding of hydrogen blending in diesel engine, FORTRAN language computer program is developed and the performance of SI engine is calculated with only gasoline and with different ratios of gasoline hydrogen mixture. An indirect injection, multi cylinder diesel engine inducted with continuous hydrogen into the inlet manifold can lead to a better approach to optimize engine performance and emission reduction [22]. Fuel for Compression Ignition C I engine can be diesel, biodiesel or vegetable oils. There are two options for the intake of Hydrogen in CI engine, one is that Hydrogen can be introduced directly along with air into the intake manifold or there could be direct injection of hydrogen into the cylinder as that done in case of diesel fuel [23]. Hydrogen gas blends are being not only widely tested with gasoline and diesel, but at the same time with other fuels such as ULSD (ultra low sulphur diesel) and PME (palm methyl ether) with a B50 and other proportions with different ratios of hydrogen [24], which are showing positive prospects like increased

brake thermal efficiency and reduced brake specific fuel consumption along with reduction in CO and CO₂. There is compatibility of hydrogen gas with both spark ignition system engine and the compression ignition system engine without any modifications induced in these internal combustion engines [25], the hydrogen blending studied to found desirable effects on performance and emission except oxides of nitrogen NO_x. Experimental results shown a steep down effects on pollution emission by the blending of hydrogen in diesel engine because of the improved and complete combustion process [26], it may be focused that a noticeable decrement in smoke levels is observed even on higher loads by hydrogen blending in diesel engine. Subas B G et al. Studied the hydrogen blended engine's formation and emission of NO_x by two methods i.e. by experimental method on experimental rig and other by the help of simulation software. In both the cases he found an increment in NO_x formation [27]. they concluded a minor difference of about 7% in the results by the two different methods. It can be drawn that the major issue on the use of hydrogen or hydrogen blend in internal combustion engine is the higher formation NO_x which is very harmful in nature for

ecology and human life which has to be addressed. By the results and conclusions from numerous studies, the major problem emerged to be increased production of NO_x during the emission from hydrogen blended fuel, the main cause for the formation of oxides of nitrogen is sought to be high cylinder temperature during its combustion [28], there should be focus on this problem, many techniques have been tried and tested for the reduction of NO_x from the hydrogen blended engine including exhaust gas recirculation (EGR) technique [29], desirable results are achieved with some conditions like extra set up for EGR. the EGR technique is used widely for NO_x reduction and reduced pumping losses but the major problem associated with it is that it shows detrimental effects on the stability of combustion in combustion chamber. Hydrogen blending to the internal combustion engine can also lead to betterment of smoke emission with full load or part load, hydrogen blend with the range of (20-25 %) found to be optimal where the smoke opacity was least with high engine performance [30]. Although It is found both at the exhaust level and In-cylinder, the addition of hydrogen increases the formation of nitrogen oxide NO_x as measured by In-cylinder gas sampling [31]

III. EXPERIMENT SETUP

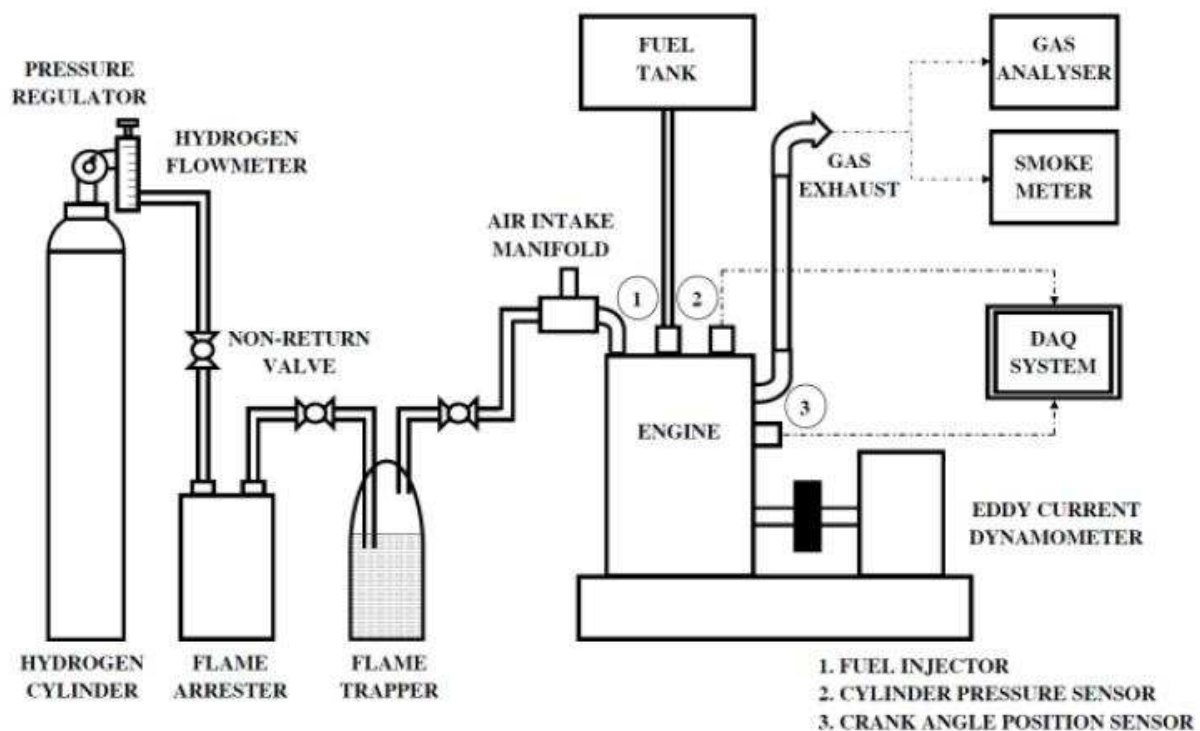


Fig.1: Schematic diagram for experimental setup



Fig.2: Actual set up for experiment

Experiments were conducted in a single cylinder, four stroke, water-cooled, diesel engine (Make: Kirloskar AV-1). The engine was coupled to an eddy current dynamometer. The engine was run at a constant speed of 1500 rpm. The specifications of the engine used are given in Table

Table: Engine Specifications

Engine Make	Kirloskar AV-1
Type	Vertical, Single cylinder, water cooled,
Max. power	3.7 kW at 1500 rpm
Displacement	550 CC
Bore x Stroke	80 mm x 110 mm
Compression ratio	16.5:1
Fuel injection timing	21deg bTDC
Loading device	Eddy current dynamometer

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 (NO_x), 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 8 lpm respectively. The hydrogen flow line consists of hydrogen cylinder, pressure regulator, flame arrester, flow meter and flow control valve shown in figure.



Fig.3: Hydrogen Gas Induction Set up

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 0–10 lpm. The combustion, performance and emission characteristics were evaluated for different hydrogen flow rates and compared with neat diesel fuel operation.

IV. RESULTS AND DISCUSSIONS

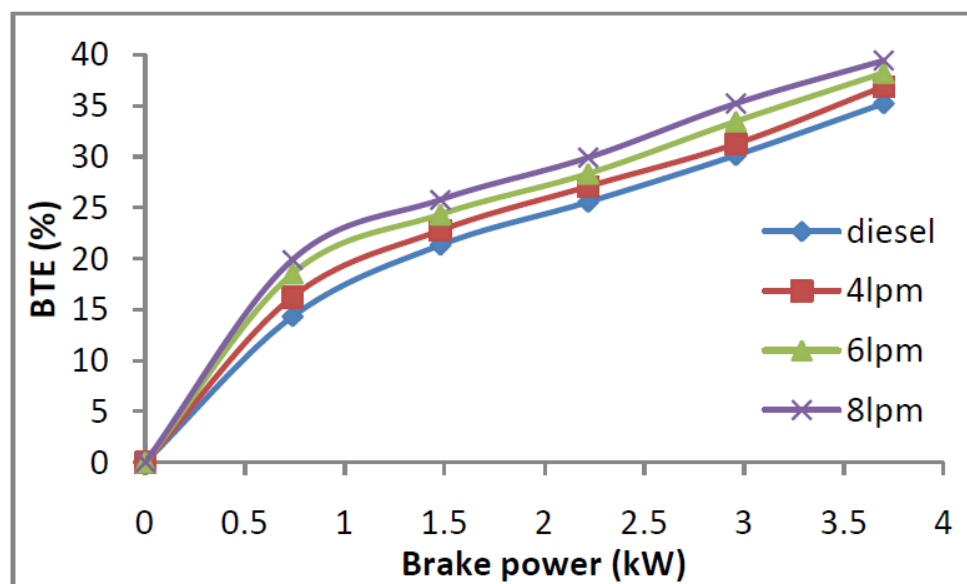


Fig.4: Variation of BTE and Brake Power with Pure Diesel and Dual Fuel

BTE (brake thermal efficiency) is plotted against the brake power for neat diesel and hydrogen added diesel. Brake thermal efficiency is one of the key in factors in getting the engine performance and it is defined as fuel

consumption rate to generate unit power .It can be observed that increase in flow rate of hydrogen in fuel increases the BTE and brake power. Increase in hydrogen flow rate causing increase in both BTE and brake power.

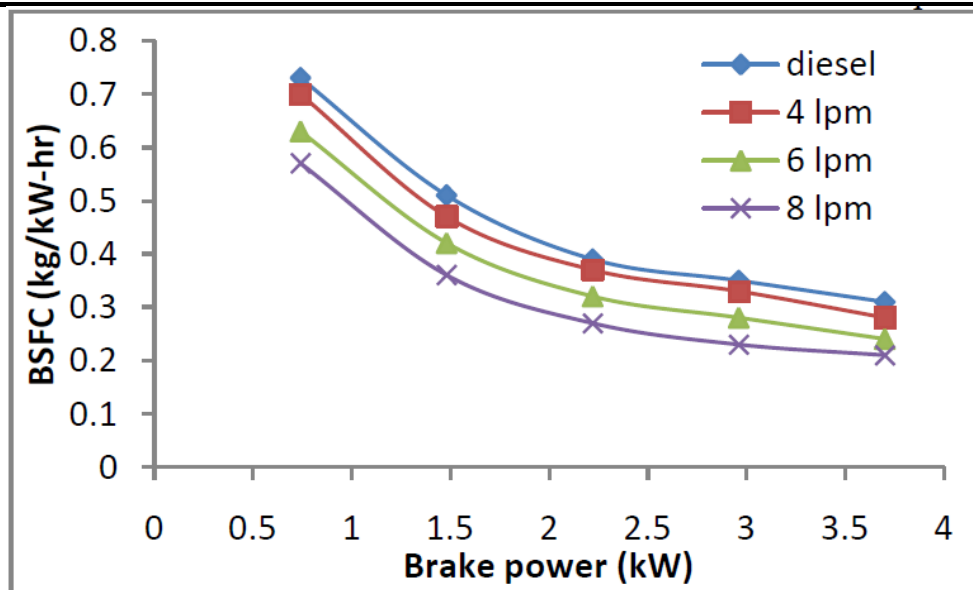


Fig.5: Variation of BSFC and Brake Power for Pure Diesel and Dual Fuel

Brake specific fuel consumption is plotted against brake power for neat diesel and hydrogen added diesel. A considerable decrease can be seen with neat diesel operation and hydrogen added diesel with 8 lpm .

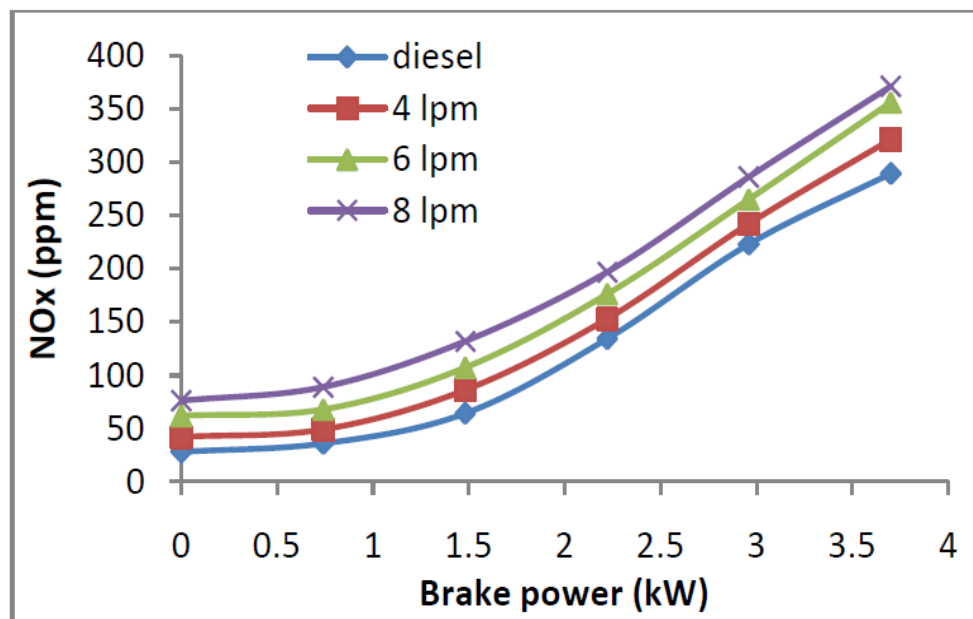


Fig.6: Variation of NOx emission and Brake Power with Neat diesel and Dual fuel

Emission of NOx is noted with respect to brake power for diesel fuel and dual fuel. it can be observed that as the flow rate of hydrogen is increased the formation of NOx is on the rise due to high in cylinder temperature is created by rapid combustion of hydrogen fuel.

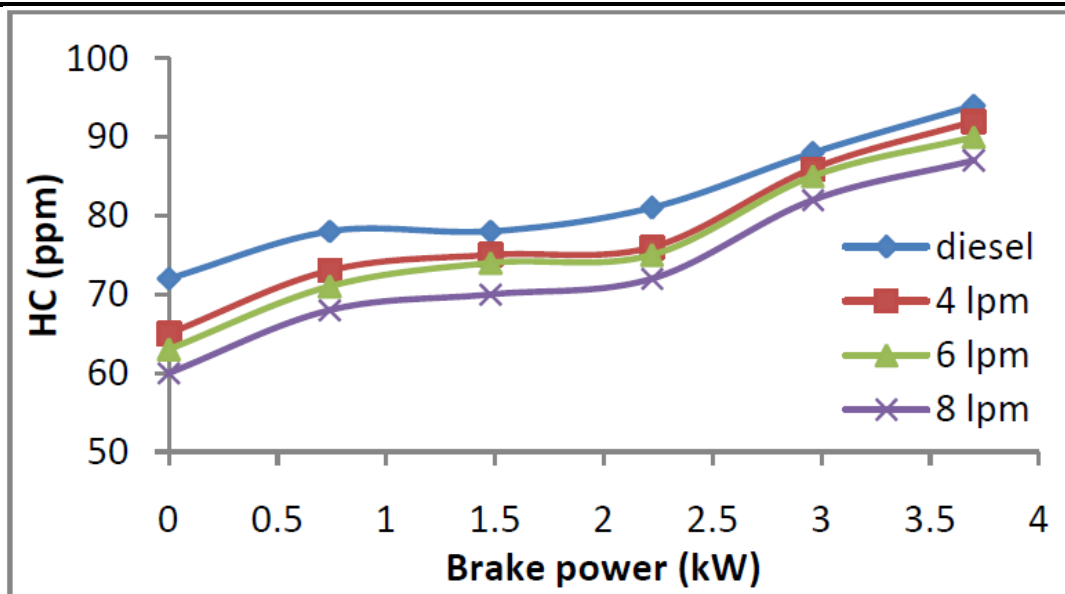


Fig.7: Variation of HC and Brake Power with neat diesel and dual fuel

HC emission is observed with respect to brake power. With boost in hydrogen addition the creation of OH- radicals are speed up and which results in decrease in HC emissions with the increase in hydrogen amount. The small quench distance of hydrogen between position of the flame extinguishment and cylinder wall helps in reducing HC emissions with the increase in hydrogen amount.

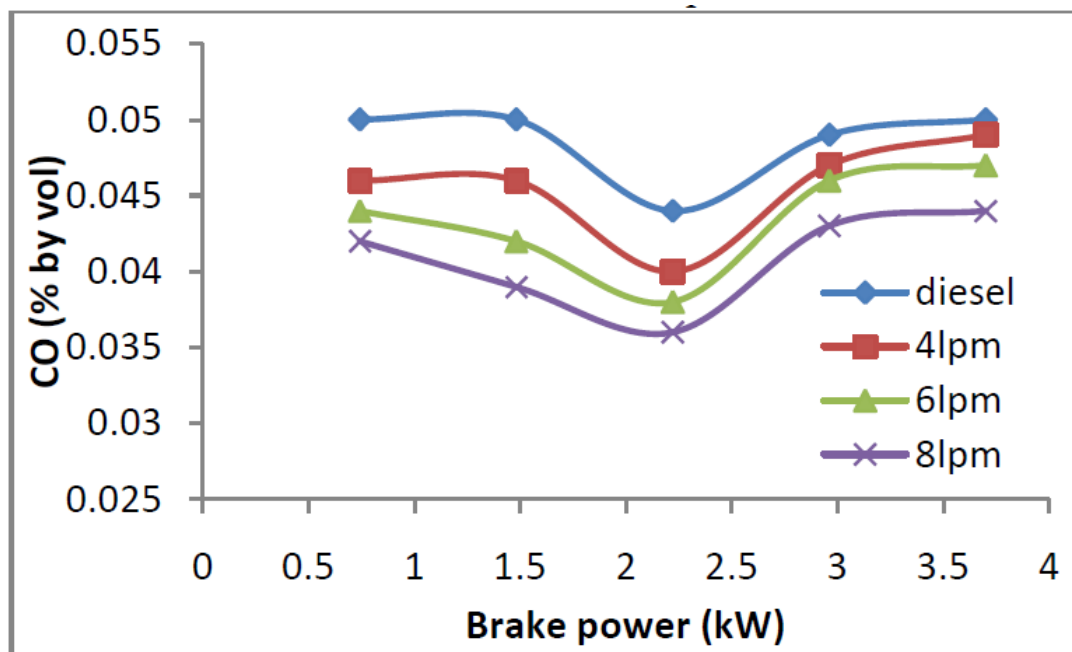


Fig.8: Variation of CO emission and Brake Power with neat diesel and dual fuel

CO emission is noted with respect to brake power. a the graph clearly shows that neat diesel have the maximum CO volume percentage and by addition of hydrogen subsequently the volume percentage is decreased further and have a maximum decrease in CO volume at 8 lpm can be observed

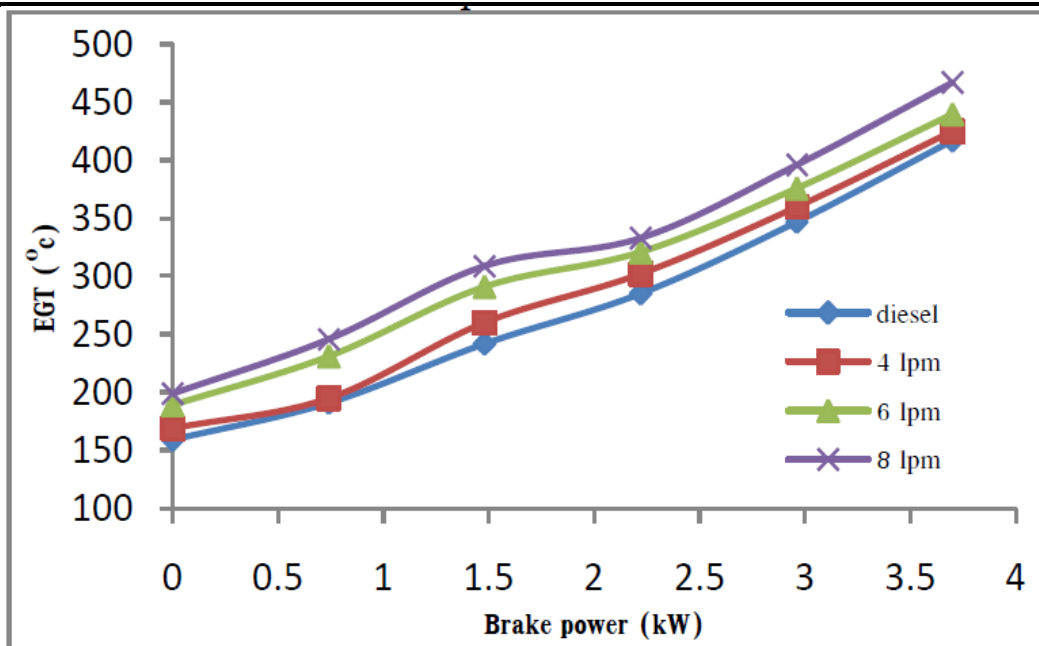


Fig.9: Brake Power vs. Exhaust Gas Temperature graph

In this graph it can be observed that on addition of hydrogen with diesel there is gradual increase in exhaust gas temperature along with the brake power.

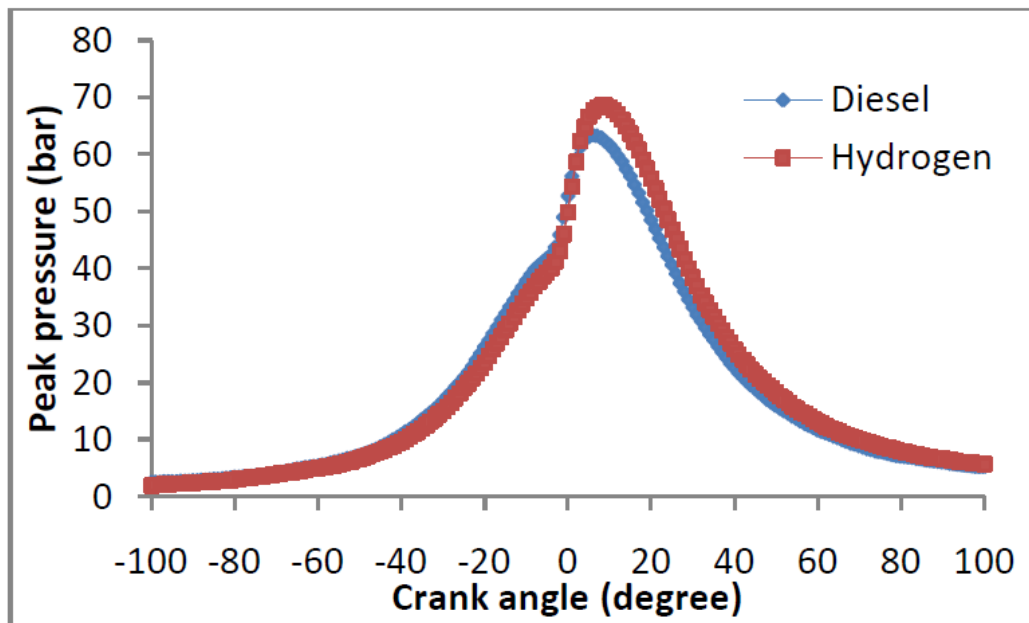


Fig.10: Crank Angle vs. Peak Pressure graph

This graph indicate the relation between crank angle and peak pressure in bar for both diesel and hydrogen, it can be read that peak pressure for hydrogen fuel is more than that of neat diesel in relation to crank angle.

V. CONCLUSIONS

Based on the experiments conducted on a hydrogen-enriched air-inducted diesel (dual fuel) 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 8 lpm 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.
- There is a decremented difference in HC and CO with the 8lpm flow rate of hydrogen in comparison to neat diesel.

VI. FUTURE SCOPE

This work addressed the right alternative for the diesel fuel in the future, more work can be performed for betterment in this regard like to control the EGT and percentage of Oxides of Nitrogen, neat nitrogen and hydrogen gas can be simultaneously introduced along with diesel.

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