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Enhancing diesel engine combustion using hydrogen enriched fuels – A Review

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Abstract: Hydrogen is hovering to become a chief constituent in the energy-mix in the coming years to meet the growing energy needs for world's economy, while protecting the environment and guaranteeing energy security. It is envisioned that hydrogen will be available for an extensive range of applications including power generation, portable, transport, and heating applications. The present paper analysesthe enhancement of diesel engine combustion using hydrogen enriched fuels. In this analysis, threefuels enriched with hydrogen were selected. They are Liquefied Petroleum Gas (LPG), Methane, and Synthesis Gas (Syn gas). In all the analysis, the results obtained by lone diesel fuel operation was taken as a base lineto examine the efficacy of the hydrogen enriched diesel fuel combustion.The analysisrevealed that the use of hydrogen enriched fuel in a diesel engine combustion, enhances the combustion phenomena of diesel engine undoubtedly.
Keywords : hydrogen enrichment;dual fuel;brake thermal efficiency; NO_X emission

Introduction

Hydrogen can compensate some of the demand for hydrocarbon fuel by being combusted along with gasoline, diesel, or natural gas in an internal combustion engine. This type of combustion is called dual-fuel combustion. It either uses very small amounts of hydrogen to modify combustion or uses a large amount of hydrogen as the principal source of energy in the combustion chamber. This type of operation has been investigated by numerous researchers for several types of hydrogen assisted combustions[1-5].The use of hydrogen as a bi-fuel needs major safety precautionary measures. Since, the ignition energy of hydrogen is very low. It may back fire during the operation of the engine. Generally, in order to avoid any catastrophe, it is advisable to use flame traps and flame arrestors. These flame traps and arrestors may be of wet type or of dry type.

National Hydrogen Energy Road Map (NHERMP) prepared by Ministry of New and Renewable Energy (MNRE) has addressed various aspects of hydrogen economy. The key objective of the programme is to identify the routes, which will lead to a gradual induction of hydrogen energy in the country, speeding up the commercialization and facilitate establishment of hydrogen energy infrastructure in the country [6]. The block diagram of total hydrogen energy system proposed by MNRE is shown in **Figure 1.** The road map has clearly pointed out that the production of hydrogen is a main area to be concentrated for hydrogen economy. It also insisted that the production of hydrogen should be made from other renewable sources such as nuclear energy, coal gasification, biomass, biological in addition to present methods of production of hydrogen.

Hydrogen Energy – Indian Scenario

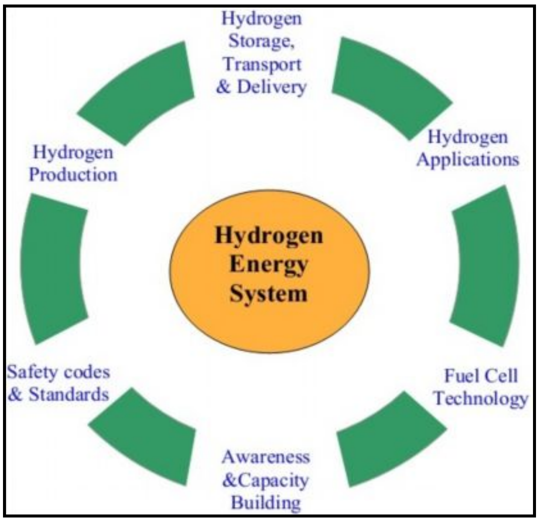

Figure 1. Block diagram of total hydrogen energy system[6]

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Current Problems of Four Stroke Diesel Engines

There have been continuous search for the most efficient prime movers right from the invention of diesel engines, which will do less harm to the environment. The research and development mainly focuses on the fuel economy and the exhaust emissions of the four stroke diesel engines.The high levels of smoke and NO_X emissions are the main drawback of diesel engines. These facts put the diesel engines under pressure to cope with the stringent emission norms. The high level of smoke emissions is due to diffusive combustion of diesel engine, whereas NO_X emissions are mainly due to high combustion chamber temperature and dissociation. It is very difficult to control simultaneously both the smoke and NO_X emission in a diesel engine due to their trade off.

Results and Discussions

Lata et al [7] made an experimental investigation on performance and emission of a dual fuel operation of a four cylinder, turbocharged, inter-cooled, 62.5 kW genset diesel engine with hydrogen, liquefied petroleum gas (LPG) and mixture of LPG and hydrogen as secondary fuels. They carried out the experiments at a wide range of load conditions of the engine with different gaseous fuel substitutions. Brake thermal efficiency at 10% load for various percentage of hydrogen enriched LPG is shown in **Figure 2.**When only hydrogen was used as secondary fuel, the maximum enhancement in the brake thermal efficiency was 17% which was obtained with 30% of secondary fuel. When only LPG was used as secondary fuel, maximum enhancement in the brake thermal efficiency was 6% with 40% of secondary fuel.

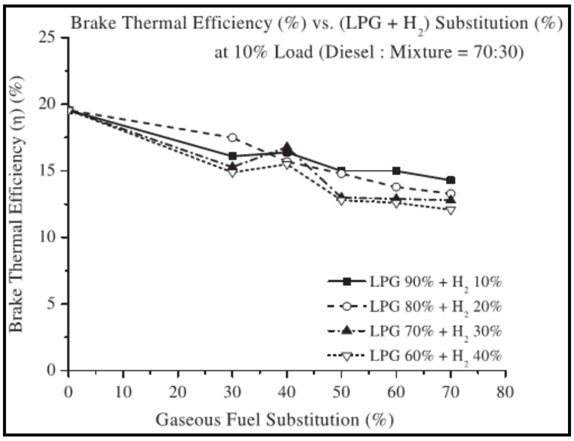

Figure 2.Brake thermal efficiency Vs gaseous fuel substitution for diesel+hydrogen LPGat 10% load condition [7]

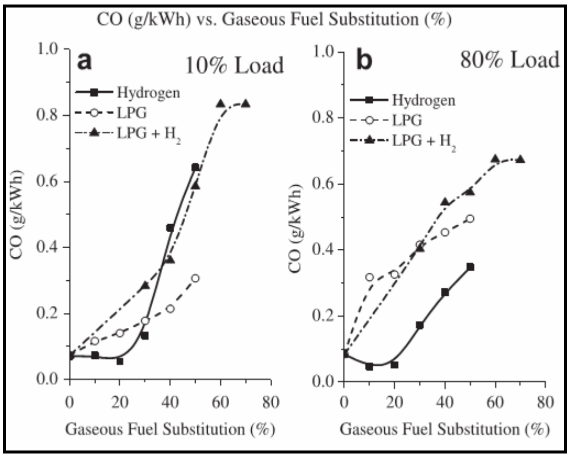

Figure 3.Carbon monoxide Vs diesel+ gaseous fuels substitution [7]

Carbon monoxide emission at 10% load and 80% load for various percentage of hydrogen enriched LPG is shown in **Figure 3.**They observed that compared to the pure diesel operation, proportion of unburnt HC and CO got increased while emission of NO_X and smoke got reduced in both cases. On the other hand, when 40% of the mixture of LPG and hydrogen was used in the ratio of 70:30 as secondary fuel, brake thermal efficiency got enhanced by 27% and HC emission got reduced by 68%. Further, they observed that the dual fuel diesel engine showed lower thermal efficiency at lower load conditions as compared to diesel.

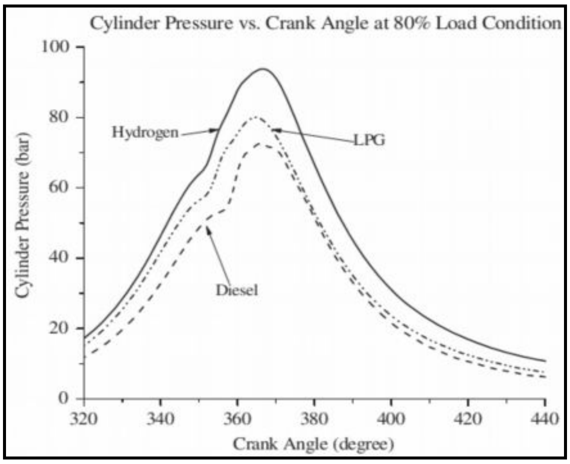

Figure 4.Cylinder pressure Vs crank angle at 80% load condition [7]

They attributed this to the fact that at low concentration of hydrogen or LPG in the intake air,the combustion spread throughout the gas-air mixture. This caused high heat transfer losses to the adjacent walls. While, in the case of diesel engines under light load condition, the penetration of the diesel spray was such that it did not reach the cylinder walls and the combustion was confined to piston bowl and also, the surrounding coatings of air acted as insulation in between burnt gases and the walls, which reduced heat losses thereby giving better thermal efficiencies with diesel. They found that this short coming of low efficiency at lower load condition in a dual fuel operation could be removed when a mixture of hydrogen and LPG was used as the secondary fuel at higher than 10% load condition. **Figure 4** displays the in-cylinder pressure versus crank angle at 80% load condition.

Zhou et al [8] conducted an experimental investigation on combustion and emission characteristics of a compression ignition engine using diesel as pilot fuel and methane, hydrogen and methane/hydrogen mixture as gaseous fuels at 1800 rpm. The test engine was mounted on an eddy-current dynamometer. They measured the in-cylinder pressure by a piezo electric sensor of Kistler make and the pressure signals were amplified with a charge amplifier. A crank-angle encoder was employed for crank-angle signal acquisition at a revolution of 0.5°CA. The intake and exhaust gas temperatures were measured by K-type thermocouples. For gaseous emissions, total HC was measured with a heated flame ionization detector. NO/NO_X was measured with a heated chemiluminescent analyzer. CO and CO_2 were measured with non-dispersive infrared analyzers. O_2 was measured with a portable gas analyzer.

During the investigation they observed that the ULSD-hydrogen combustion became unstable and hard to control at high loads.When hydrogen was enriched in methane, the BTE got increased at all loads.**Figure 5** depicts the effect of hydrogen-methane mixture on brake thermal efficiencyat various BMEP condition of the engine. With the addition of hydrogen into methane, the peak cylinder pressure got increased relativeto ULSD-Methane operation and this effect was more apparent at 90% load. **Figure 6** portrays the effect of hydrogen-methane mixture on heat release rate. At BMEP of 0.71 MPa, for ULSD-Methane dual-fuel engine, the peak heat release rate increased apparently compared with the baseline operation.

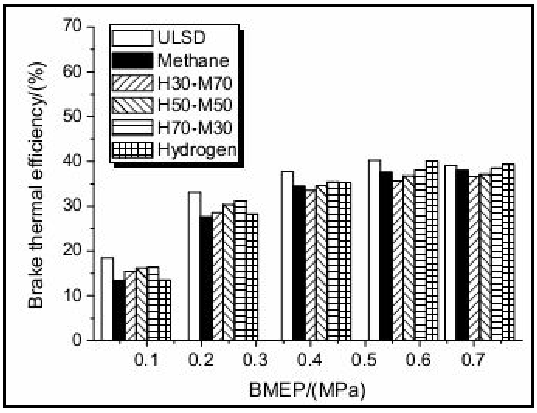

Figure 5. Effect of hydrogen-methane mixture on brake thermal efficiency [8]

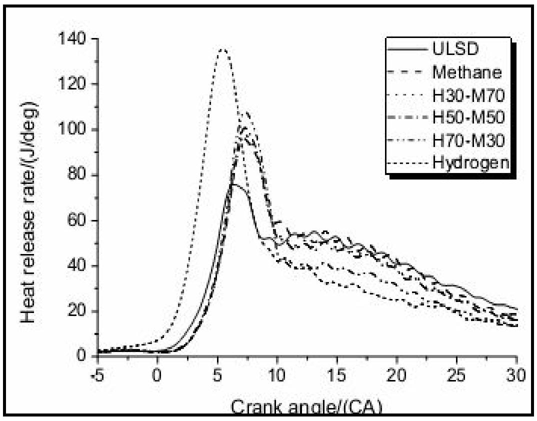

Figure6. Effect of hydrogen-methane mixture on heat release rate [8]

The heat release rate profile for ULSD-Hydrogen revealed that the main combustion phase occurred at premixed combustion phase and the heat released during diffusion combustion phase was reduced a lot relative to other cases. They found that the CO emission increased sharply when the combustion of methane and ULSD had taken place. This was due to the incomplete combustion of methane. When ULSD-Hydrogen was combusted in dual-fuel mode, the CO emission decreased at all load sowing to the direct replacement of the carbon content from hydrogen to diesel fuel. The addition of hydrogen into the methane extended the flammability limit of methane and the incomplete combustion of methane was alleviated. When the engine was operated at 90% of the full load with hydrogen induction, CO emission got reduced by nearly 25% compared to base line operation.

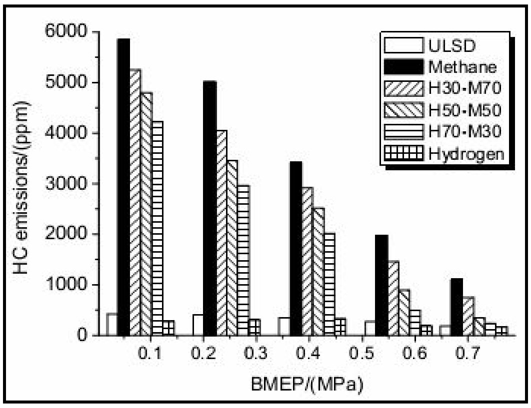

Figure 7. Effect of hydrogen-methane mixture on total HC emission [8]

Figure 7 exhibits the effect of hydrogen-methane mixture on total HC emission.The total HC emission was high when ULSD-methane was combusted. On the other hand, when ULSD-Hydrogen was combusted, the total HC emission got decreased. For the BMEP of 0.08 MPa, 0.24 MPa and 0.41 MPa, the total HC emission was 12.01, 10.26, 9.03, 7.69, and 0.78 times than baseline for Methane, H30-M70, H50-M50, H70-M30 and Hydrogen, respectively. For ULSD-Methane and ULSD-Hydrogen dual-fuel combustion, NO_X emission got decreased slightly at lower load and increased at medium to high loads. This was due to the higher combustion temperature and faster burning rate of hydrogen [9] than methane, ULSD-Hydrogen combustion enhanced the NO_X formation. When small quantity of hydrogen was mixed with methane, it reduced NO_X emission. But, when the quantity of hydrogen was increased, the NO_X emission got increased. At H50-M50 case, the NO_X was basically the same with ULSD-Methane operation.

Plaksin et al [10] conducted a study on reduction of NO_X in diesel engine emissions by using a hydrogen-rich synthesis gas produced by plasmatron fuel reformer. They activated 10% to 20% of the diesel fuel in an arc discharge and turned them into plasma chemical reformation fuel by using a DC arc plasmatron that was fabricated to increase the ability of gas activation. They got the yielding of diesel fuel reformation up to 80% to 100% when small quantity of diesel fuel in range of 6 ml/min was used. They supplied this synthesis gas mixture which contained hydrogen, carbon dioxide, carbon monoxide, nitrogen, and hydrocarbons into the engine together with the rest of the fuel-air mixture.

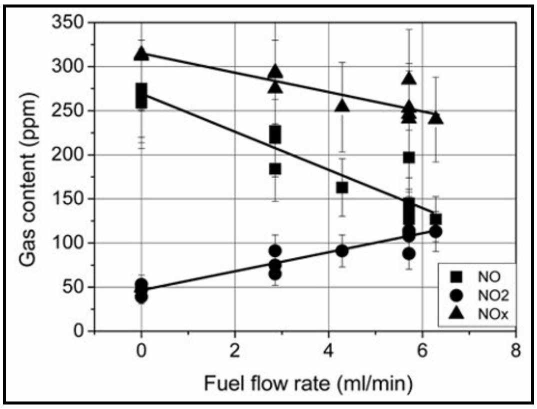

Figure 8. Nitrogen oxide content Vs fuel flow rate at Q_F=0-6 ml/min [10]

Figure 8 portrays nitrogen oxide content Vs fuel flow rate at Q_F=0-6 ml/min. From the figure it is evident that there was a decrease in the NO_X content in the emissions of the engine up to 23%.

Conclusions

The present analysis of hydrogen enriched fuel combustion in diesel engine reveals the following results.

- Hydrogen enriched fuels can be used in an unmodified diesel engine.
- When hydrogen enriched fuel is used in a bi fuel mode, it increases Brake thermal efficiency and reduces Brake specific energy consumption.
- Due to instantaneous combustion of hydrogen, the heat release rate of hydrogen enriched fuels are high.
- In overall, NO_X emission gets increased due high in-cylinder temperature.
- When hydrogen enriched fuels are used, smoke emission gets decreased.

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