Available online at www.sciencedirect.com

ScienceDirect

Procedia Earth and Planetary Science 11 (2015) 385 – 392

Procedia
Earth and Planetary Science

Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources (GCPF2015)

Hydrogen Induction to Diesel Engine Working on Bio Diesel: A Review

Rachan D Shekar[a], H R Purushothama[b]

[a]Department of Mechanical Engineering, Adichunchanagiri Institute of Technology, Chikmagalur-577102, India
[b]Department of Mechanical Engineering, Siddaganga Institute of Technology, Tumkur-572105, India

Abstract

Biodiesel is the latest trend in the pursuit of finding an alternative to the existing fossil diesel or mineral diesel oil as it is depleting in a rate faster than its rate of replacement. In doing so there is a chance of reduction in the over efficiency of the engine which may be in terms of combustion, performance and emission. This review paper presents hydrogen as an additive to the bio-diesel mixture. It also gives the various methods of inducing hydrogen as explained in detail in this review paper.

Peer-review under responsibility of organizing committee of the Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources.

*Keywords:*Biodiesel; Hydrogen; Induction

1. Introduction

Fossil fuels are one of the major sources of energy production, but in the recent years the fossil fuel reserves are depleting at a much rapid rate than its restoration so the recent scenario is towards the production of an alternative for the fossil fuel which can be renewed easily and available locally such as biodiesel, alcohols etc.

Biodiesel is methyl or ethyl ester of fatty acid made from virgin or used vegetable oils (both edible and non-edible) and animal fat. The main source of biodiesel is the non-edible oils extracted from plant species. Biodiesel can be blended in any proportions with the mineral or petroleum diesel to form a biodiesel blend or can even be used in its pure form. Pure biodiesel or biodiesel blends can be used in the regular Compression Ignition engine with very little or no modification at all. The properties of the biodiesel are almost same as that of diesel and can be stored easily like the conventional diesel. More than 300 million species of plants produce seeds having oil content. These oils are either edible or non-edible. Edible oils are used for human consumption and cannot be thought of using for energy generation so non edible oils are given emphasis upon. There are many non-edible oils that are produced in India extensively like Neem (Azardircachata Indica Juss), Honge (Indian Beech) etc., are suitable to be used in Compression Ignition engine. These non-edible oil plants are renewable, readily grown in India.

Peer-review under responsibility of organizing committee of the Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources.
doi:10.1016/j.proeps.2015.06.037

The use of biodiesel in the conventional diesel engine has the advantage of reduction in the emission of unburned hydrocarbons, carbon monoxide and particulate matter but it has a major disadvantage of reducing the overall efficiency of the conventional engine and in order to overcome this reduction in the efficiency hydrogen can be introduced into the engine in different ways like aspiration of hydrogen from the cylinder (readily available in the cylinder) into inlet manifold along with air during the suction stroke, use of hydrogen based chemicals like water or hydrogen peroxide, extraction of hydrogen by splitting of hydrogen based compounds like water.

Nomenclature

H_2	Hydrogen
O_2	Oxygen
BTDC	Before Top Dead Centre
ATDC	After Top Dead Centre

2. Literature review

Nagaprasad K S and D Madhu[1] conducted an experiment on a four stroke multi-cylinder, water cooled compression ignition engine operated with neat diesel and blends of hydrogen peroxide with diesel. They investigated the performance of diesel engine by injecting hydrogen peroxide as blends with diesel at 2%, 5% and 10% proportions. In the experiments, injection timing was also changed which is an important parameter in the study. Results showed that, the efficiency of engine increased by injecting hydrogen peroxide at all fractions along with diesel and the exhaust gas temperature has found to be decreased reasonably. Also efficiency of engine has increased by advancing the injection timing by five deg for both diesel and its blend with hydrogen peroxide. At injection timing of 150 BTDC, engine was unable to start when 2% and 5% of hydrogen peroxide with diesel is injected.

Hsin-Kai Wang et.al., [2] investigated the emission reductions of polycyclic aromatic hydrocarbons (PAHs), hydrocarbons (HCs), carbon monoxide (CO), carbon dioxide (CO_2), particulate matters (PM), and nitrogen oxides (NOx) from a heavy-duty diesel engine (HDDE) at one low load steady-state condition, 24.5% of the maximum load (40 km/h), using premium diesel fuel (PDF) mixed with various amounts of H_2/O_2. Measurements showed that the mixed fuel of HO60 reduced the brake specific fuel consumption (BSFC) most, by an amount of 12.6% as compared with PDF. Meanwhile, with HO60 the emission of air pollutant was deceased by 32.3% for PAHs, 9.5% for HCs, 7.2% for CO, 4.4% for CO2 and 19.3% for PM but the emission of NOx was increased by 9.9%.

Probir Kumar Bose et.al.,[3] Stimulated active research interest in non-petroleum, carbon free compounds and non-polluting fuels, particularly for transportation, power generation and agricultural sectors. Environmental concerns and limited amount of petroleum fuels have caused interests in the development of alternative fuels for internal combustion (IC) engines. Hydrogen was used in an internal combustion engine based power trains due to its superior combustion qualities like it's very high laminar flame speed, impose specific operating strategies and the adaptation of the conventional research tools and availability. They injected hydrogen into the intake manifold of a single cylinder diesel engine using an injector following the TMI(Time Manifold Injection) technique. Using an electronic control unit (ECU) the injection timing was varied at 100,450and 800ATDC and the duration were controlled. From the results they observed that the optimum injection timing with 800ATDC.They investigated the combustion and performance characteristics of Diesel engine using hydrogen diesel dual fuel mode.

R Adnan et.al.,[4]worked towards increasing the performance and reducing pollutant emissions of diesel engine. Port injection gaseous fuel system is one of the solutions and it is applicable for dual fuel combustion engines. In this study, series of experiments were carried out to study the effect of continuous port injection hydrogen gas on in-cylinder pressure and emissions of unmodified single cylinder diesel engine. Injection of hydrogen resulted an increase in in-cylinder peak pressure in the range of 5 to 23 bars and exhaust gas temperature in the range of 3.1% to 10.2% throughout all engine speeds. There were also increases in NOx, CO and CO2 emissions due to presence of hydrogen ranges between 50 to 200 ppm, 420 to 760 ppm and 1.1% to 4.2% (by volume) respectively. On the other hand, continuous port injection hydrogen addition in diesel engine showed reduction of hydrocarbon (HC) at the average of 15 ppm and O2 emissions at the average of 6% (by volume).

Sompop Jarungthammachote et.al.,[5]Tried to reduce diesel fuel consumption by using an alternative energy sources such as Hydrogen (H_2) and promoted to use as dual-fuel system. H_2 is considered as a fuel for future because it is more environmental friendly compared to carbon-based fuel. However, the most exiting diesel engines were designed for using diesel fuel. Feeding H_2-diesel dual fuel to the engine, it is required to study its effect on engine operation parameters. Moreover, it is also an interesting point to observe the engine emission when H_2-diesel dual fuel is used. The thermodynamic modelling was used to simulate the operating parameters, i.e., cylinder pressure and gas temperature. Finite different method was employed to find the solution. The H_2 supply and EGR were varied. The pressure and temperature were observed. For NOx emission which is a major problem for use of diesel engine, the thermodynamic equilibrium calculation was conducted to find the mole fraction of gas species in the exhaust gas. The mole fraction of NO and NO_2 were combined to present as the mole fraction of NOx. The simulation showed that at 5% EGR, increase of H_2 caused increase of cylinder pressure and temperature. It also increased NOx in exhaust gas. However, when H_2 was fixed at 10%, increasing EGR led reducing of cylinder pressure and temperature. The mole fraction of NOx decreased with increasing EGR.The H_2 supplied to the engine provided positive effect on the engine power indicated by increasing pressure and temperature. However, it showed the negative effect on NOx emission. Use of EGR was recommended for controlling NOx emission when H_2 is supplied.

W.B. Santoso et.al.,[6]studied hydrogen as a great potential in the near future. They studied hydrogen utilization as diesel engine fuel. Hydrogen cannot be used directly in a diesel engine due to its auto ignition temperature higher than that of diesel fuel. One alternative method is to use hydrogen in enrichment or induction. To investigate the combustion characteristics of this dual fuel engine, a single cylinder diesel research engine was converted to utilize hydrogen as fuel. Hydrogen was introduced to the intake manifold using a mixer before entering the combustion chamber. The engine was run at a constant speed of 2000 rpm and variable loads. At each load step the flow rate of hydrogen was varied. Fuel consumption, injector needle lift movement and cylinder pressure were measured. Introducing hydrogen to the combustion chamber reduced the diesel fuel consumption. Indicated efficiency slightly increases with hydrogen enrichment at 15 Nm load. At lower load the efficiency decreases. Specific energy consumption increases with increase in hydrogen flow rate at 5 and 10 Nm load. Inversely, it decreases at higher load. Cylinder pressure decreases with hydrogen enrichment at 5 and 10 Nm but slightly increases at higher load.

Duraid F. Maki et. al., [7] studied the hydrogen induction set up in the lab with all of the acquitting sensors and measuring instruments. The safety rules were considered. A continuous hydrogen induction in the inlet manifold was selected as a technique for this investigation. Experimental tests were done to investigate engine thermal performance and exhaust emission constituents under those blend circumstances. The optimum operating conditions and optimum parameters for those blends were found. It was found out that the optimum rate of hydrogen induction is 7.5 lpm. This optimum rate reduced the diesel fuel consumption by 20 % and increased the brake thermal efficiency by about 8-9%. They also observed that NO_x emission was reduced.

Haroun A.K. Shahad and Nabeel Abdul-Hadi [8] carried out experiments to evaluate the influence of the addition of hydrogen to the inlet air on the performance of a single cylinder direct injection diesel engine. Hydrogen was injected in the inlet manifold. The addition of hydrogen was done on energy replacement basis. It was found that the addition of hydrogen improves the combustion process due to superior combustion characteristics of hydrogen in comparison to conventional diesel fuels. It was also found that 10% energy replacement improves the engine thermal efficiency by about 40% and reduces the sfc by about 35%; however the volumetric efficiency was reduced by about 35%.

Mihaylov Milen and Barzev Kiril[9] carried out experiments to evaluate the influence of the addition of hydrogen oxygen mixture (obtained from electrochemically decomposed water) to the inlet air of a single cylinder direct injection diesel engine. Addition of hydrogen to the in-take or delivery into the cylinder of diesel engine improved combustion process due to superior combustion characteristics of hydrogen in comparison to conventional diesel fuels.

N Saravanan et.al.,[10]studied a Direct Injection (DI) diesel engine for its performance and emissions in dual-fuel (Hydrogen-Diesel) mode operation. Hydrogen was injected into the intake port along with air, while diesel was injected directly inside the cylinder. Hydrogen injection timing and injection duration varies from a wider range with constant injection timing of 23˚ before injection Top Dead Centre (BITDC) for diesel fuel. When hydrogen is used as a fuel along with diesel, they observed that the emissions of Hydro Carbon (HC), Carbon monoxide (CO) and oxides of Nitrogen (NO_x) decrease without exhausting more amount of smoke. The maximum brake thermal efficiency obtained is about 30% at full load for the optimized injection timing of 5^o After Gas Exchange Top Dead Centre

(AGTDC) and for injection duration of 90^o crank angle. The NO_x emission tends to reduce to a lower value of 888 parts per million (ppm) at full load condition for the optimized injection timing of 5^o AGTDC and with an injection duration of 90^o compared to neat diesel fuel operation.

Jacob Wall[11] studied the addition of hydrogen has been shown to decrease the formation of NOx, CO and unburned hydrocarbons. He observed that added hydrogen in percentages as low as 5-10% of the hydrocarbon fuel can reduce that hydrocarbon fuel consumption. The theory behind this concept is that the addition of hydrogen can extend the lean operation limit, improve the lean burn ability and decrease burn duration. He conducted the Research by allowing the hydrogen to be reformed from the vehicles hydrocarbon fuel supply or produce hydrogen from electrolysis of water. He suggested that in the future, better methods could be developed for storing hydrogen in the vehicle or production of hydrogen on-board the vehicle.

P S Ranjit and Mukesh Saxena[12] studied about the Hydrogen utilization in compression ignition engines. They used hydrogen as the supplement and sole modes in these engines. They studied the effects on engine performance and emission variations and their remedies with reference to hydrogen introduction and induction in the compression ignition engines. They also studied the importance of indirect injection engine with reference to application of alternative fuels.

Gandhi Pullagura et.al.,[13] studied the effect of hydrogen at the constant flow rate of 4 1pm inducted in the intake, at a distance of 40 cm from the intake manifold, along with air. Two different fuels, i.e., first 40% blend of used transformer oil (UTO 40) and 60% diesel fuel and the second was neat Used transformer oil (UTO 100) were tested as main fuels in single cylinder, 4-stroke, air cooled direct injection diesel engine developing a power of 4.4 KW, rated speed of 1500 rpm. The performance and emission parameters of the engine were obtained in the investigation and compared with the diesel fuel.

Chaisermtawan P et.al.,[14] theoretically analysed the hydrogen-diesel dual fuel combustion with exhaust gas recirculation. They employed a chemical equilibrium method to estimate exhaust gas products from diesel and hydrogen-diesel mode combustion in a presence of exhaust gas portion. They investigated the combustion products, e.g. unburned hydrocarbons (in terms of methane, CH_4), hydrogen (H_2), carbon dioxide (CO_2), carbon monoxide (CO) etc., based upon equivalent specific energy input. Those products were subsequently used to calculate combustion efficiency, based upon chemical energy left in the waste exhaust gases. Their main findings were associated with the reduction in CH_4, CO_2, and CO corresponding to the increase in combustion efficiency in hydrogen-diesel combustion mode. Meanwhile, they found that hydrogen content in flue gas may increase in some operating conditions.

Biplab K. Debnath et.al.,[15] performed experiments on a compression ignition diesel engine with dual fuel mode. Diesel and hydrogen were used as pilot liquid and primary gaseous fuel respectively. They found out the specific composition of diesel and hydrogen for maximum brake thermal efficiency at five different loading conditions (20%, 40%, 60%, 80% and 100% of full load) individually on the basis of maximum diesel substitution rate. They also studied the effects on brake specific fuel consumption, brake specific energy consumption; volumetric efficiency and exhaust gas temperature were also observed at various liquid gaseous fuel compositions for all the five loadings. Second law analysis was carried out to optimize the dual fuel engine run. They observed that a diesel engine can be run efficiently in hydrogen-diesel dual fuel mode if the diesel to hydrogen ratio is kept at 40:60.

S. Bari and M. Mohammad Ismaeil[16] Used hydrogen as an additive to enhance the conventional diesel engine performance and the outcomes were very promising. On-board hydrogen–oxygen generator which produces H_2/O_2 mixture through electrolysis of water was used to overcome the problems associated with the production and storage of hydrogen. They focused on evaluating the performance enhancement of a conventional diesel engine through the addition of H_2/O_2 mixture generated through water electrolysis. The experimental works were carried out under constant speed with varying load and amount of H2/O2 mixture. Results show that by using 4.84%, 6.06% and 6.12% total diesel equivalent of H_2/O_2 mixture the brake thermal efficiency increased from 32.0% to 34.6%, 32.9% to 35.8% and 34.7% to 36.3% at 19 kW, 22 kW and 28 kW respectively. They obtained 15.07%, 15.16% and 14.96% fuel savings. The emissions of HC, CO_2 and CO decreased whereas the NOx emission increased.

Gandhi Pullagura et.al.,[17] produced Esters of vegetable oil and bio oil by pyrolysis of various biomass resources which have greater scope as alternative fuels for the future in power and transportation sectors. They conducted experiments to evaluate the combustion parameters of a compression ignition engine fuelled with biodiesel-bio oil emulsion and hydrogen on a dual fuel mode. Hydrogen was inducted in small quantities in a diesel engine whereas an emulsion of bio-oil and methyl ester of karanja was injected into the cylinder as a main fuel. The impact of dual fuel mode on rate of pressure rise, peak pressure, ignition delay and heat release rate of the engine were studied. The results were compared with diesel fuel operation.

Widodo Budi. Santoso et.al., [18] Studied the cyclic variability of a diesel engine fuelled with hydrogen and ignited by diesel spray. To investigate the combustion characteristics of this dual fuel engine, they converted a single cylinder diesel research engine to utilize hydrogen as fuel. Hydrogen was introduced to the intake manifold using a mixer before entering the combustion chamber. The engine was run at a constant speed of 2000 rpm and variable loads. At each load step the flow rate of hydrogen was varied. An engine indicating system was used to measure and record the cylinder pressure up to 160 consecutive combustion cycles. The combustion data for each operating conditions were analyzed for the maximum cylinder pressure and indicated mean effective pressure (IMEP). The cycle-by-cycle variation was expressed as the mean value, standard deviation, coefficient of variation of these two parameters. They found that cyclic variability is reduced at higher engine load operation.

Haroun A. K. Shahad and Nabil Abul Hadi[19]studied about the pollutants emitted from internal combustion engines which becomes increasingly important since it affects human life on earth directly and indirectly through air pollution, global warming, acid rains etc., for the blended hydrogen gas with hydrocarbon fuels used in internal combustion engines. They carried out experimental research to study the effect of hydrogen blending. A four stroke air cooled diesel engine was used in this program. The engine was run at different loads, speeds and hydrogen blending percentages. It was found that increasing the blending percentage reduces the emitted concentration of carbon oxides and smoke. However it was found that nitrogen oxides concentration was increased with increasing hydrogen blending percentage due to higher cylinder temperatures. The results showed that 10% hydrogen blending reduced smoke opacity by about 65%, increased the nitrogen oxides concentration by about 21.8% and CO_2 and CO concentrations were reduced by about 27% and 32% respectively. This trend was found at all tested speeds and loads.

Masood M et.al.,[20]studied about the drawback of lean operation with hydrocarbon fuels that is a reduced power output. Lean mixtures are hard to ignite, despite the mixture being above the Low fire (point) limit of the fuel and these results in misfire which increases un-burned hydrocarbon emissions, reducing performance and wastes fuel. They used hydrogen in conjunction with compact liquid fuels such as gasoline; alcohol or diesel provided each is stored separately. Mixing hydrogen with other hydrocarbon fuels reduced all of these drawbacks. Hydrogen's low ignition energy limit and high burning speed made the hydrogen/hydrocarbon mixture easier to ignite reducing misfire and thereby improving emissions, performance and fuel economy. Regarding power output, hydrogen augmented the mixture's energy density at lean mixtures by increasing the hydrogen-to-carbon ratio and thereby improved torque at wide-open throttle conditions. They simulated a program for determining the mole fraction of each of the exhaust species when the hydrogen is burnt along with diesel. The proportion of hydrogen in the hydrogen-diesel blend affecting the mole fraction of the exhaust species was also simulated. Experimental investigations were carried out in hydrogen – diesel dual fuel mode which showed a good agreement between the predicted and experimental results. The program code developed was found valid for any combination of dual fuels.

N Saravanan and G Nagarajan[21] carried out experiments using hydrogen in the dual fuel mode in a Diesel engine system. They converted a Diesel engine into a dual fuel engine and hydrogen fuel was injected into the intake port while Diesel was injected directly inside the combustion chamber during the compression stroke. Diesel injected inside the combustion chamber underwent combustion first which in-turn ignited the hydrogen that also assisted the Diesel combustion. Using electronic control unit (ECU), the injection timings and injection durations were varied for hydrogen injection while for Diesel the injection timing was 23^{o} crank angle (CA) before injection top dead centre (BITDC). Based on the performance, combustion and emission characteristics, the optimized injection timing was found to be 5^{o} CA before gas exchange top dead centre (BGTDC) with injection duration of 30^{o} CA for hydrogen Diesel dual fuel operation. The optimum hydrogen flow rate was found to be 7.5 lpm. They observed that the brake thermal efficiency in hydrogen Diesel dual fuel operation increased by 15% compared to Diesel fuel at 75% load. The NO_X emissions were higher by 1–2% in dual fuel operation at full load compared to Diesel. Smoke emissions were lowered in the entire load spectra due to the absence of carbon in hydrogen fuel. The carbon monoxide (CO), carbon dioxide (CO_2) emissions were lesser in hydrogenDiesel dual fuel operation compared to Diesel. They concluded that the use of hydrogen in the dual fuel mode in a Diesel engine improves the performance and reduces the exhaust emissions from the engine except for HC and NO_X emissions.

N. Saravanan et.al.,[22] experimentally used hydrogen-enriched air as intake charge in a diesel engine adopting exhaust gas recirculation (EGR) technique with hydrogen flow rate at 20 l/min. Experiments were conducted in a single-cylinder, four-stroke, water-cooled, direct-injection diesel engine coupled to an electrical generator. Performance parameters such as specific energy consumption, brake thermal efficiency are determined and emissions such as oxides of nitrogen, hydrocarbon, carbon monoxide, particulate matter, smoke and exhaust gas temperature were measured. Usage of hydrogen in dual fuel mode with EGR technique results in lowered smoke level, particulate and NOx emissions.

Bibhuti B. Sahoo et.al.,[23]usedSyngas at different loads and studied the effect of syngas on the performance, combustion and emission characteristics of a diesel engine. For this purpose, three different volumetric compositions of syngas fuels were examined in the diesel engine under dual fuel modes. The syngas with 100% H2 compositions showed an improved engine performance but at the expense of higher NOx emissions for an increase in load. The NOx emissions reduced when 25% and 50% CO were added in the 100% H2 composition syngas. At the best efficiency loading point of 80%, the maximum diesel replacement was found as 72.3% for 100% H2 syngas mode. At same engine load, the thermal efficiency was found to be 16.1% for 50% H2 syngas. It increased to 18.3% and 19.8% when H2 content was increased to 75% and 100% respectively. At higher loads, the 50% and 75% H2 content syngas modes showed a good competitive performance to that of 100% H2 mode. The higher CO and HC emission levels were recorded for 25 and 50% CO fraction syngas fuels due to their CO content in the fuel compositions. At part-loads (20% and 40% loads), all the tested ranges of syngas modes resulted in a poor performance including higher emission levels.

Horng-Wen Wu and Zhan-Yi Wu[24] added hydrogen in an intake manifold and designed an exhaust gas recirculation (EGR) system for a direct injection diesel engine. The cylinder gas pressure, air mass flow, fuel mass flow, and emissions (such as CO, CO2, HC, NOX, and smoke) were measured under various engine loads and 0% to 40% EGR ratios adjusting the hydrogen-energy-share ratio at 0% to 20% which means that the energy of hydrogen replaced 0% to 20% that of diesel fuel. The combustion characteristics such as cyclic variations, heat release rate, brake thermal efficiency and specific fuel consumption (SFC) were determined. The results showed that the variation coefficient values of indicated mean effective pressure (IMEP) are from 0.9% to 2.8%. The rate of decrease in the smoke emission is 37.6% and that in the NOX emission is 59.5% for a 60% load, 40% EGR ratio, and 20% added hydrogen.

N Saravanan et.al.,[25] compared the performance and emission characteristics of a DI diesel engine with gaseous hydrogen as a fuel inducted by means of carburetion technique and timed port injection technique (TPI) along with diesel as a source of ignition. They studied the specific energy consumption, NOx emission and observed that the exhaust gas temperature increased by 6%, 8% and 14% respectively and brake thermal efficiency and smoke level reduced by 5% and 8% respectively, using carburetion technique compared to baseline diesel. But they observed that in the TPI technique, the specific energy consumption, exhaust gas temperature and smoke level reduced by 15%, 45% and 18%, respectively. The brake thermal efficiency and NOx increased by 17% and 34% respectively, compared to baseline diesel. They also observed that the emissions such as HC, CO, and CO_2 are very low in both carburetion and TPI techniques compared baseline diesel.

2.1. Conclusions on literature review

By the detailed literature review it can be said that hydrogen can either replace diesel totally as a fuel in the CI engine or can be used as a additive either in the form of gas along with atmospheric air or mixed with the fossil diesel fuel oil.

3. Various methods of hydrogen induction

Hydrogen can be inducted into an engine in the following ways-

- Mixing of Hydrogen based chemicals like water, hydrogen peroxide into fossil diesel as an additive.
- Splitting of hydrogen from water by the process of electrolysis and injecting the gaseous mixture of H_2-O_2 to the engine through the inlet manifold along with atmospheric air.
- Directly injecting gaseous hydrogen readily available in the cylinders into the engine through the inlet manifold along with atmospheric air.

3.1. Mixing of hydrogen based liquid compounds with the fuel

It involves the mixing of Hydrogen based compounds like water, Hydrogen Peroxide etc into the biodiesel mixture as an additive. At higher temperatures, these liquid compounds will liberate hydrogen-oxygen mixture thereby enhancing the performance of the engine. The major advantage of this kind of Hydrogen induction is that no change in the design of the engine is required; an added advantage is that as there is a presence of oxygen complete combustion of the fuel air mixture can be assured. The major disadvantage being that, if this chemical proportion increases the fluid physical, chemical and combustion characteristics of the mixture will be altered.

3.2. Splitting of hydrogen and injection into the engine

It involves the splitting of water into Hydrogen-Oxygen mixture by the process of electrolysis and injecting it into the engine cylinder through the inlet manifold along with atmospheric air. Here atmospheric air is replaced instead of the fuel by H_2-O_2 mixture. It has an advantage of enhancing the performance and combustion characteristics of the engine. The in-cylinder pressures and temperatures of the engine all increased thereby improving the overall efficiency of the engine. But due to the presence of oxygen in the mixture, complete combustion is ensured but it may also lead to the increase in NOx emissions of the engine which is a major environmental concern. Another major disadvantage is that handling of hydrogen is a very difficult task as it can easily combust at room temperatures. If proper precautions are not taken while transporting hydrogen into the engine cylinder there is a chance of explosion of the entire set up. In order to overcome the above said disadvantages various measures like flame arrestor etc, is used to avoid back fire.

3.3. Injection of hydrogen from the cylinder

It involves the injecting of hydrogen gas directly from the readily available hydrogen gas from the cylinder. In this case the atmospheric air is replaced by gaseous hydrogen and not the fuel. The in-cylinder pressures and temperatures of the engine all increased thereby improving the overall efficiency of the engine. But since the calorific value of hydrogen is high, it leads to higher temperatures of exhaust gases and may also lead to the increase in NOx emissions of the engine which is a major environmental concern. Another major disadvantage is that handling of hydrogen is a very difficult task, as it can easily combust at room temperatures. If proper precautions are not taken while transporting hydrogen into the engine cylinder there is a chance of explosion of the entire set up. In order to overcome the above said disadvantages various measures like flame arrestor etc is used to avoid back fire.

4. Conclusions

By analyzing the various alternatives of hydrogen induction, each alternative has its own advantages and limitations. Mixing of Hydrogen based compounds is relatively simple but the amount of replacement is very minimal compared to other alternatives. Injection of hydrogen along with atmospheric air through the inlet manifold would improve the performance, combustion characteristics of the engine but exhaust emissions, fuel handling and alteration of the engine setup is of major concern. It is suggested to use Exhaust gas recirculation in the case increased NOx emission.

References

1. Nagaprasad K S and D Madhu*"Effect of Injecting Hydrogen Peroxide into Diesel Engine"* , IJESET, vol.2, issue1, April2012, pp. 24-28
2. Hsin-Kai Wang, Chi-Yu Cheng, Yuan-Chung Lin, Kang-Shin Chen *"Emission reductions of Air pollutants from a Heavy-duty diesel engine mixed with various amounts of H_2/O_2"*, Aerosol and Air Quality Research 2012.pp. 133-140
3. Probir Kumar Bose, Rahul Banerjee, Madhujit Deb "Combustion and Performance Analysis of Hydrogen Direct Injection with Diesel as an Ignition Source at a Particular Injection Timing with Varying Injection Durations", Advances in Natural and Applied Sciences 2011.pp. 227-234
4. R adnan, H HMasjuki and T M I Mahlia*"Experimental Investigation on In-Cylinder Pressure and Emissions of Diesel Engine with Port Injection Hydrogen System"*, International Journal of Mechanical and Materials Engineering (IJMME)Vol.5, 2010.pp. 136-141
5. SompopJarungthammachote, SathapornChuepeng and PrateepChaisermtawan*"Effect of Hydrogen Addition on Diesel Engine Operation and NO_x Emission: A Thermodynamic Study"* American Journal for Applied Sciences 9, 2012.

6. W.B Santoso, A.Nur, S.Ariyono, R.A. Bakar"Combustion Characteristics of a Diesel-Hydrogen Dual Fuel Engine", NCMER 2010.pp. 23-32
7. Duraid F. Maki, P. Prabhakaran"An Experimental Investigation on Performance and Emissions of a Multi Cylinder Diesel Engine Fueled with Hydrogen-Diesel Blends", World Renewable Energy Congress, Sweden, 2011pp.3557-3564
8. Haroun A.K. Shahad, Nabeel Abdul-Hadi "Experimental Investigation of the Effect of Hydrogen Manifold Injection on the Performance of Compression Ignition Engines" World Academy of Science, Engineering and Technology 76 2011pp. 277-282
9. MihaylovMilen and BarzevKiril "Investigation of the Effects of Hydrogen Addition on Performance and Exhaust Emissions of Diesel Engine"Fisita World Automotive Congress, Barcelona 2004.
10. 10. N. Saravanan, G. Nagarajan, C. Dhanasekaran and K. M. Kalaiselvan*"Experimental Investigation of Hydrogen Fuel Injection in DI Dual Fuel Diesel Engine"* SAE International Journal 2007.
11. Jacob Wall *"Effect of Hydrogen Enriched Hydrocarbon Combustion on Emissions and Performance"* Department of Biological and Agricultural Engineering, University of Idaho.
12. P.S. Ranjit and MukeshSaxena"A Review on Hydrogen Utilization in Internal Combustion Compression Ignition Engines" IJSTM, Vol.3 Issue.2, September 2012.
13. Gandhi Pullagura, Kakelli Ravi Kumar, Piyush Chandra Verma, AbhashJaiswal, R. Prakash, S Murugan*"Experimental Investigation of Hydrogen Enrichment on Performance and Emission behavior of Compression Ignition Engine"*, International Journal of Engineering Science and Technology Vol 4 No.03, March 2012.pp. 1223-1232
14. Chaisermtawan P, Kiatiwat T, Jarungthammachote S and Chuepeng S "Insight into Emissions and Combustion Efficiency of Hydrogen-Diesel Dual Fuel Engine with Exhaust Gas Recirculation using Chemical Equilibrium Analysis" The Second TSME International Conference on Mechanical Engineering, Krabi 2011.
15. BiplabK.Debnath, Ujjwal K. Saha, NiranjanSahoo "Effect of Hydrogen-Diesel quantity variation on brake thermal efficiency of a dual fuelled diesel engine" Journal of Power Technologies92(1). 2012.pp.55-67
16. S.Bari and M. Mohammad Esmaeil*"Effect of* H_2/O_2 *addition in increasing the thermal efficiency of a diesel engine"*www.elsevier.com/locate/fuel(89) 2010pp. 378-383
17. Gandhi Pullagura, BabjiAlapati, MahendraBabuKantipudi, Prakash R *"Effect of Hydrogen enrichment on the combustion characteristics of a bio-fuel diesel engine"* pp.001-006 IOSR Journal of Engineering Vol.2 Issue 1, Jan.2012.
18. Widodo Budi Santoso, Rosli Abu Bakar, SugengAriyono and NurCholis*"Study of Cyclic Variability in Diesel-Hydrogen Dual Fuel Engine Combustion"*, IJMME-IJENS Vol.12, No.04, August 2012pp. 52-56
19. Haroun A. K. Shahad and Nabil AbulHadi "Experimental Investigation of the Effect of Hydrogen Blending on the Concentration of Pollutants Emitted from a Four Stroke Diesel Engine" JJMIE Vol.5, No.1, February 2011pp.71-76
20. Masood M, Ishrat M M, Reddy A S "Computer Simulation of Hydrogen-Diesel Dual fuel Exhaust Emissions with Experimental verification" International Conference on Energy and Environment 2006
21. N. Saravanan, G Nagarajan*"Performance and emission studies on port injection of hydrogen with varied flow rates with Diesel as an ignition source"* www.elsevier.com/locate/apenergy, 2010pp.2218-2229
22. 22. N. Saravananetal."An experimental investigation on hydrogen as a dual fuel for diesel engine system with exhaust gas recirculation technique"www.elsevier.com/locate/rene33 2010pp.422-427
23. Bibhuti B. Sahooetal. *"Effect of* H_2*:CO ratio in syngas on the performance of a dual fuel diesel engine operation"*, www.elsevier.com/locate/apthermeng, 2012pp.139-146
24. Horng-Wen Wu and Zhan-Yi Wu "Investigation on combustion characteristics and emissions of diesel/hydrogen mixtures by using energy-share method in a diesel engine" www.elsevier.com/locate/apthermeng 2012pp.154-162
25. N. Saravananetal.*"An experimental investigation of DI diesel engine with hydrogen fuel"*www.elsevier.com/locate/rene(38) 2008. Pp.415-421