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A review on analysis of HHO gas in IC engines

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Abstract

The over usage of fossil fuel and the resulting drastic increase in pollution levels has made us realize the need for a new sustainable fuel which does not cause pollution. This search ended up with an innovative idea of using Brown gas as a fuel enhancer in internal combustion engines which uses fossil fuels as a primary source for combustion. Many developments have been made in this area with several experiments on gasoline as well as diesel internal combustion engines till now using HHO gas or brown gas as a fuel performance enhancer. This work involves the review of various developments which has taken place in this field. With the addition of HHO gas there was a net increase in brake power ranging from (2% to 5.7%) and increase in brake thermal efficiency which ranges from (10.26% to 34.9%). A decrease in specific fuel consumption was observed which ranged from (20% to 30%) along with a decrease in CO and HC emissions on an average of 18%and 14%respectively.

Selection and/or Peer-review under responsibility of International Multi- Conference on Computing, Communication, Electrical & Nanotechnology: Materials Science.

Keywords: HHO ; Brown gas

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1. Introduction

The over usage of fossil fuel and the resulting drastic increase in pollution levels has made us realize the need for a new sustainable fuel which does not cause pollution. This search ended up with an innovative idea of using Brown gas as a fuel enhancer in internal combustion engines which uses fossil fuels as a primary source for combustion. Brown gas or commonly known as HHO gas is a mixture of hydrogen and oxygen obtained by the process of electrolysis. HHO gases will combust when ignited producing water vapor and heat energy as products. The most innovative breakthrough in the HHO technology came in the last few decades distinguishing it from the older techniques of electrolysis which were expensive, inefficient and required high amount of electric power. For example researchers have developed new method that uses aluminum and a liquid alloy (gallium-indium-tin alloy) to extract hydrogen from seawater. Two chemists at Princeton University have identified a new catalyst (iron-doped nickel oxide) which speeds up the electrolysis process. Scientists at the University at Buffalo have shown how spherical silicon particles of about 10 nanometers in diameter can react with water to produce hydrogen on an almost instantaneous basis. In another case new type of solar-powered electrode has been developed which generates an electric current that separate the water into its constituent parts of hydrogen and oxygen. [1,2,3,4]. Also by using new HHO reactor configurations and modern electronic circuits HHO gas can be produced very efficiently which puts this as a promising energy source. Adding HHO gas to the engine enhances the combustion process increases the brake power and reduces the harmful emissions. The HHO gas constitutes of Hydrogen and Oxygen. Hydrogen has the highest calorific value as well as a high flame speed. Oxygen supports combustion making more fuel molecules to take part in the combustion process leaving less un burnt hydrocarbon. This paper briefly discusses about the previous work carried out by the researchers in the various fields which are related to the topic and helped one gain to build platform for my work.

2. Review on literature

2.1 Petrol Engine

Mohamed et al [5] The study focused up on the addition of HHO gas when it was added with petrol to the IC engine. They used two types of electrolyte for the better efficiency of the electrolysis process and found that 6 g/L of KOH as catalyst gives better efficiency at different engine speeds. They also found that 4 g/L of NaOH gives better thermal efficiency as compared to other NaOH concentration at different engine speeds. The use of HHO gas in conventional engines gave the following results. The engine thermal efficiency had been increased up to 10% when HHO gas has been introduced into the air/fuel mixture, consequently reducing fuel consumption up to 34%.The concentration of NO_x, CO and HC gases has been reduced to almost 15%, 18% and 14% respectively on average when HHO is introduced into the system. The best available catalyst was found to be KOH, with concentration 6 g/L.

Sharma et al [6] investigated the effect of hydroxyl gas addition on different performance characteristics of a four stroke multi-cylinder SI engine. With their experiments following results were formed. The brake power of the engine has been enhanced by almost 11.5% on average. The specific fuel consumption of engine has been decreased by almost 6.35% on average. The brake thermal efficiency of engine has been increased by almost 10.26% on average. The exhaust gas temperature from engine has been reduced by almost 4% on average. This is due to improved burning of fuel which further leads to significant reduction in NO_X emission from exhaust gas.

Bhardwaj et al[7] Their work focused on evaluating the performance enhancement of a petrol engine through the addition of brown gas generated by water electrolysis. On the basis of experimental analysis the following conclusions were made. It has been observed that brown gas can be mixed with gasoline safely. Substantial results are obtained using mixture of brown gas and gasoline fuel. Reduction in power output was observed due to lower volumetric heating value. Indicated Thermal Efficiency increased due to increase in ratio B.P to F.P. Spark retardation i.e. optimum spark timing was used due to increase in flame burning velocity. With the increase of the A/F ratio, the ignition delays and combustion duration increases. It is found that there was a reduction in CO_2, CO & HC due to direct displacement of carbon based fuel with H2.Exhaust HC and CO_2 concentrations increased with the increase of hydrogen fraction at high engine load.

Musmar et al [8] The team did experimental tests to investigate the effect of HHO gas on the emission parameters of a Honda G 200 engine. The generated HHO gas was mixed with a fresh air just before entering the carburetor. The exhaust was sampled by a gas analyzer and the exhaust constituents had been identified and their concentration was evaluated. The results show that nitrogen monoxide (NO) and nitrogen oxides (NO_X) have been reduced to about 50% when a mixture of HHO, air, and fuel was used. Moreover, the carbon monoxide concentration had been reduced to about 20%. Also a reduction in fuel consumption had been noticed and it ranged between 20% and 30%.

Prasad et al [9]The performance and emission characteristics of conventional petrol and HHO gas were investigated on a four stroke single cylinder S.I engine without any modifications and without storage tanks. Their major finding was the average reduction of 6.7% is obtained in HC emission compared to pure gasoline operation. Without any load variations, thermal efficiency increases with induction of hydroxyl gas in the case of petrol. An average gain of 16.3% is achieved in S.F.C by using HHO system. An average reduction of 6.7% is obtained in HC emissions compared to pure gasoline operation.

Chetan et al [10] The team investigated the effects of HHO addition with gasoline in a petrol engine. Some interesting conclusions have been made on the emission analysis test. It was found out that there is an increase in emission level of carbon dioxide nitrogen oxides. But there was decrease in emission level of unburnt hydrocarbons and carbon monoxide .This has been tested with different grades of petrol and the results have been plotted in fig 1.

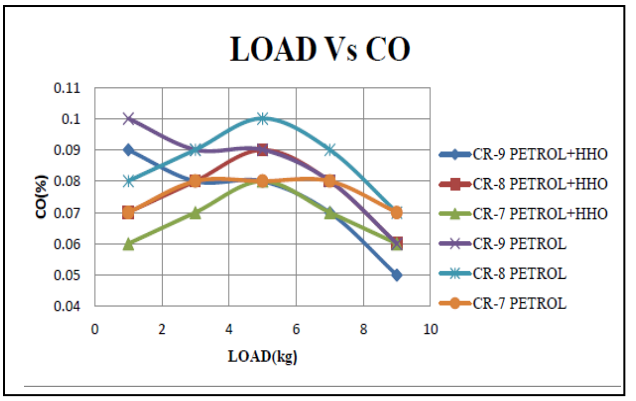

Fig. 1. Load Vs CO graph [10]

Dabur et al. [11] In their experiment a comparison is made on Petrol , LPG, HHO fuels on the basis of performance and emission for single cylinder 4 stroke 110 cc maestro. After the comparison the following results were obtained. It enhanced the engine performance in terms of brake power, mechanical efficiency, indicated power and knocking characteristics. The maximum brake thermal efficiency for 110cc maestro is observed. 55% with petrol, 62% obtained by LPG and HHO gives 51.7%.With increment of brake thermal efficiency and carbon monoxide, unused oxygen and hydrocarbons smoke reduces with increases in additives. Emission of CO2 and NOX is found minimum for HHO fuel. Mechanical efficiency against load is maximum for HHO fuel with 78% where LPG with 72% and Petrol with 63.8%.

Maheshkumar et al[12] . Their experiment was the addition of HHO gas in a gasoline engine. The use of hydrogen in gasoline engines enhanced the combustion efficiencies, consequently reducing the fuel consumption by 20%.Use of hydrogen in gasoline engines lead to reduction in emission of harmfull pollutants such as carbon monoxide and unburnt hydrocarbons. Use of hydrogen in gasoline engine increased the power output of the engine around 5.7% and thermal efficiency increased around 5%.

Aaditya et al[13]. In this paper they have studied the basic properties of gas generated through electrolysis of water and then used this gas in the a bike as a fuel supplement with gasoline by mixing it with air. The HHO reactor was made from high grade stainless steel and NaOH was used as an electrolyte. They reported an increased mileage of bike 30 to 60% and reduced the polluting contents from the exhaust gases.

Seralathan et al[14]. The paper dealt with the aspect of increasing the speed of the conventional motorcycle by keeping the related performance considerations. An engine of 223cc, 17 hp with a top speed of 125 kmph had been chosen. HHO gas generator was installed in the setup and gear ratios were chained to obtain the following results. The modifications carried out on the conventional motorcycle have increased the performance of the vehicle. The speed of the vehicle increased till 170 km/h with the changed gear ratios. The vehicle gives a better mileage as well as a decrease in emissions.

Dhananjay et[15] The experiment was done on a 4 stroke SI engine with HHO gas as a fuel supplement. Interesting results had been formed which has been listed out. The use of HHO in gasoline engines increased combustion efficiencies, consequently decreasing fuel consumption by 20%. Use of HHO in gasoline engines lead to reduction in emission of harmful pollutants such as carbon monoxide and unburnt hydrocarbons. Use of HHO in gasoline engine increased the power output of the engine around 5.7%. Thermal Efficiency increased around 5% .The increases in thermal efficiency and the reduced SFC has been plotted in the graphs shown. Refer figure 2

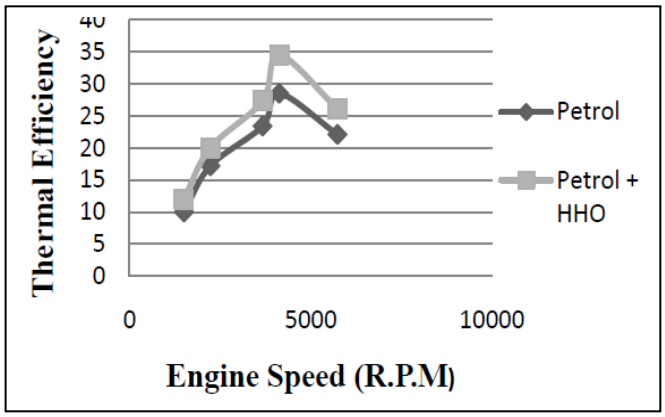

Fig. 2. Thermal efficiency Vs RPM [15]

Abhishek et al.[16] They experimented on the addition of HHO gas in a TVS victor 109cc engine . Iincreased mileage, increased horsepower, reduced emissions were obtained while providing a quieter and cleaner engine. The main emphasis of this paper was the theoretical calculations done for determining the HHO output. These calculations have shown that for a Current of 4.5amps during a period of 216.5 seconds, the electrolysis of water yields 0.25 Liters of hydrogen gas and 0.063 Liters of oxygen gas.

Pranay et al. [17] In this study, Hydroxy gas (HHO) was produced by the electrolysis process of different electrolytes (KOH(aq), NaOH(aq), NaCl(aq)) with various electrode designs in a leak proof Plexiglas reactor (hydrogen generator). Hydroxy gas was used as a supplementary fuel in a four cylinder, four stroke, spark ignition (SI) engine without any modification Its effects on exhaust emissions and engine performance characteristics were investigated. The specific fuel consumption was reduced by about 20 to 30% when running with HHO since lower heating value of HHO is very high relative to that gasoline. Traces of HC emission were seen at HHO operation due to vaporisation of the lubricating oil. As the lubrication oil is passed into combustion chamber, some very little emission was observed when running with the HHO. The engine efficiency was increased by about 10 to 30% when running with the HHO.

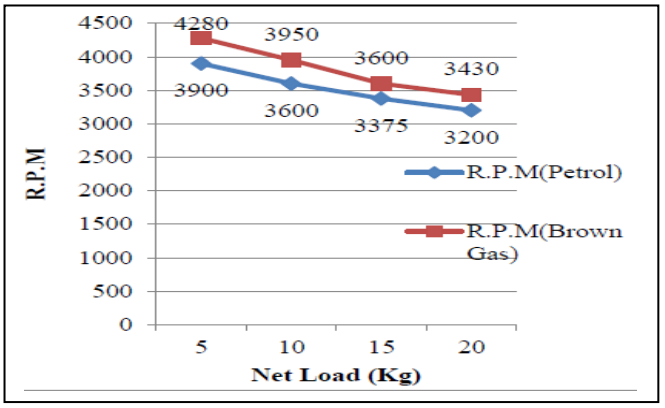

Fig. 3. Load s RPM [17]

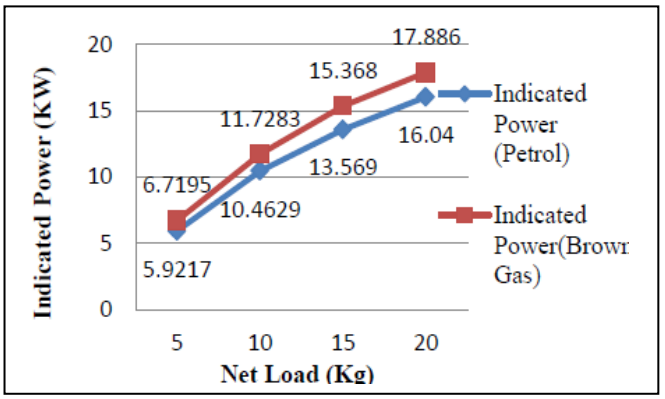

Fig. 4. Indicated power Vs. Net Load [17]

Bambang et al [18]. Dry cell HHO gas generator performance optimization was done by varying the duty cycle of pulse width modulation, PWM. HHO gas generated subsequently applied to the Sinjai spark ignition engine port injection, 2-cylinder 650 cc with gas inlet mechanism using a venturi. Variations performed on HHO gas generator is the duty cycle of PWM, i.e. 20%, 40%, 60%, 80% and 100% (or the same as non PWM). The parameters of performance were calculated includes specific energy input, efficiency and temperature of the HHO generator. HHO gas is obtained then used as a fuel mixture in the Sinjai engine and inserted through a venture mechanism which was mounted on the duct of combustion air inlet. Furthermore, the effect of the addition of HHO gas on the performance of the Sinjai engine measured includes parameters of torque, power, BMEP, specific fuel consumption and thermal efficiency. The results show that optimum performance of HHO gas generator is generated by PWM system with 40% duty cycle with parameters such as specific energy input of 33,121 MJ/kg, generator efficiency of 20,064% and generator temperature can be maintained below 600C. Application of HHO gas generator in point above on standard ignition timing Sinjai engine produce an increase of performance such as torque, power, BMEP and thermal efficiency respectively of 2.27%, 2.76% and 3.05% and a decrease of BSFC 7.76 %. Retarded ignition timing is adjusted to MBT is able to increase performance such as torque, power ,thermal efficiency, respectively 6.55%, 7,65%, 15,50% and a decrease of BSFC 22,06 %.

Gowtham et al[19]. Their proposed system used HHO gas as an additive fuel for running IC engine of 153cc. The following results were obtained. Actual mileage of the bike is 39.4 km/l at normal conditions of fuel and air intake. When hydroxyl gas is fed in to air intake the mileage of bike is 50.6 km/l. Therefore mileage difference of 11.2 km/l is arrived, increasing the mileage efficiency about 25 to 26%. Their work mainly focused on the specific fuel consumption in a single cylinder 4 stroke engine.

Silva et al [20]. Their work focused on designing a HHO reactor for a spark ignition engine .In their first implementation, the electrodes, neutral plates and the valves were designed using zinc coated iron. The generator was powered up for 24 hours with a 30g of KOH mixed in 500 ml of water. It was observed after the test that zinc coated iron used in the generator causes to corrode the metallic areas during the electrolysis process. Hence, in order to prevent this dilemma each metallic part in the design was built using stainless steel for further analysis .The generator was tested for various conditions and the results were tabulated as shown in the figure

Table 1 .Dependency of distance between the plates using two electrode method [20]

Distance between plates	Production o HHO	Maximum current flow	Time taken
5 mm	1 litre	1.8 A	20 min
2.5 mm	1 litre	6 A	4 min

Table 2. Production of HHO with current consumption with number of electrodes needed. [20]

Number of electrodes	Production o HHO	Maximum current flow	Time taken
2	1 litre	2 A	20 min
3	1 litre	6 A	4 min

Table 3. Dependency of temperature [20]

Distance between plates	Production o HHO	Amount of temperature increased
5 mm	1 litre	15 ^{0}C
2.5 mm	1 litre	5 ^{0}C

Bansode et al. [21] This paper deals with the optimization of different electrode material and electrolytic solution for electrolysis of water for production of oxy-hydrogen gas, which is further blended with conventional fuel like petrol or diesel. Performance test of internal combustion engine is conducted for evaluating efficiency, mileage and exhaust emission. Different materials are used for reactor design and stainless steel 316 grades were selected. Performance tests with HHO addition and without HHO addition were done and the results are tabulated below in the figure

Table 4. Engine performance without HHO [21]

Sl. No:	Fuel consumption (Kg/hr)	Brake power (KW)	Specific fuel consumption (Kg/KW hr)	Indicated power (KW)	Mechanical efficiency (%)	Break thermal efficiency (%)	η_{it} (Indicated thermal efficiency %)
1	0.312	0.91	0.34	1.61	56	24	43.5

Table 5. Engine performance with HHO [21]

Sr no	Fuel consumption (Kg/hr)	Brake power (KW)	Specific fuel consumption (Kg/KW hr)	Indicated power (KW)	Mech effi. (%)	Break thermal effi. (%)	η_{it}
1	0.26	0.91	0.286	1.61	56.52	22.8	42.5

Tiwari et al.[22] In this project, effects of HHO gas on combustion emission in gasoline engine are analysed . The Petrol engine performance and emission analysis are conducted with Petrol + HHO and petrol respectively. Then the performance and emission analysis results are compared after conducting the tests with petrol on reduction of fuel consumption in gasoline + HHO and petrol respectively. And concluded the following results. Use of HHO in gasoline engine increases the power output of the engine around 5.7%. The HHO gas kit can be easily constructed and easily integrated with existing engines at low cost. Thermal Efficiency increases around 5%.

Sandhu[23]An experimental study on the performance, combustion and emission characteristics of a natural gas fuelled engine supplemented with 0%, 5%, 10%, 15% and 20% hydrogen supplementation was conducted. The main results are summarized as follows. The timed manifold injection through electronic fuel injection was very advantageous for the smooth operation of the engine. The BTE increase with the increasing hydrogen percentage. This increase in BTE is more pronounced in the leaner region. The emissions of CO and HC decreased with the increasing percentage of hydrogen. The increasing percentage of hydrogen resulted in the increased emissions of NO_x. NO_x level is very low at lean mixture. CNG has slower laminar burning velocity and higher ignition energy, both of which have negative effects on the engine's lean burn capability and thus the aim of low CO and NO_x can't be realized. At the present stage, the use of neat hydrogen as a fuel in IC engine seems to be a long term prospect mainly due to its undesirable properties and thus the fear attached with its usage. The blending of hydrogen in CNG can be very much beneficial for increasing the lean burn limit and for a tradeoff relation between HC, CO and NO_x emission.

1.2 Diesel Engine

Naseeb kahn et al[24] .Their study they used B20 as pilot fuel in single cylinder diesels engine and they added hydrogen at 15 liter per minute and compared the brake thermal efficiency brake specific fuel consumption and No_x emission different injection opening pressure. 33 percentage increases in break thermal efficiency was achieved. the maximum brake thermal efficiency is noted at 220 bars injection opening pressure (IOP) and the minimum brake thermal efficiency is noted at 200 bars injection opening pressure (IOP) brake specific fuel consumption is reduced to 37 % when hydrogen at 15 liter per minute is added with the pilot fuel .brake specific fuel consumption is low at 200 Bars IOP .There is reduction in exhaust gases except No_x .

Ali et al[25].Their study focused up on the production of HHO gas by a the presence of different electrolytes :KOH and NaOH , NaCl .The load test was conducted on both petrol and diesel engine and they found out the performance. For spark ignition engine an average of 32.4% increment in engine torque is obtained with using HHO system compared to pure gasoline operation. This means an increment of 27% in average engine power during the experiments compared to pure gasoline operation is achieved .For compression ignition engine an average of 19.1% increment in engine torque is obtained with using HHO system compared to pure diesel operation .An average gain of 16.3% is achieved in SFC by using HHO system. At mid and higher engine speeds, the HHO system with diesel fuel and gasoline provided higher engine torque output compared to pure diesel and gasoline fueled engine operation unless HECU is added to the system. The overall power increment in test engines during

experiments was bigger than the electrical power consumed and fuel economy obtained with the aid of HHO system as well. This indicates that the system is efficient.

Manu et al [26].The experiments was conducted on a 553 cc single cylinder constant speed Kirloskar engine .Based upon the experimental result they listed out their findings. The maximum Brake Thermal Efficiency was obtained 34.99 % at a load of 14.7 kg (3.7 kW) with HHO gas flow rate of 2 LPM. Higher BTE is attributed to better mixing of hydrogen with air which results in better combustion and also hydrogen enriched engines has an excellent lean burning ability which increases its thermal efficiency. The overall saving of diesel fuel obtained was 13.23 % at a load of 5.65 kg with HHO gas flow rate of 2 LPM. With the addition of HHO gas, some amount of diesel fuel will be replaced by HHO gas which results in decreased diesel consumption .The minimum BSFC observed was 0.254 kg/kWh with diesel fuel and it was reduced to 0.234 kg/kWh with the addition of HHO gas. It was concluded that the harmful emissions such as carbon dioxide and carbon monoxide got reduced which explains hydrogen as an eco-friendly fuel that can be the design of future engines.

Tayfun et al.[27]In this study the performance characteristics, exhaust emission characteristics and combustion process of the engine fueled with hydrogen-diesel blends were compared to diesel fuel. Hydrogen can be effectively used as additive to diesel fuel, which improve the performance and exhaust emission characteristics of DI engine. NO_x and CO emissions are reduced by using hydrogen.

Reddy et al[28]. In the proposed experiment the HHO gas is injected into the inlet manifold of the combustion chamber of 4 stroke diesel engine through the air filter. They compared the fuel consumption rate under normal operation with diesel as primary source and with diesel and HHO gas. They got a net 12.08% net decrease in fuel consumption. The brake power decrease was observed in one of the cases in performance test conducted. Minimization of carbon deposition in the cylinder was observed along with increased life of engine oil.

Rashad [29]et al. This study was carried out to evaluate the influence of adding HHO gas into the inlet air on the performance of a direct injection diesel engine. The experimental work was carried out under constant speed with varying load and amount of introduced HHO generated through water electrolysis. The maximum power of the engine decreased with using HHO. This may be due to the lower amounts of excess air available in the cylinder, and the loss in volumetric efficiency due to the displacement of intake air by the large volume of oxyhydrogen in the intake mixture. The specific fuel consumption decreased at low load (up to 20%) but at higher loads the decrease in the specific fuel consumption was not noticed .Therefore the final conclusion of this experiment was that adding oxyhydrogen can only improve the performance of the internal combustion engines at low loads.

Rahul R. Shitole[30] et al. In this report, HHO kit is tested for single cylinder Diesel Engine. Hydroxyl (HHO) gas is supplied along with inlet Air to the engine. Hydrogen Generator is used to separate H2 & O2 from the water. This separated HHO is then flowed through safety devices & finally supplied to Engine. From the results obtained on single cylinder four stroke diesel engine, it was seen that the hydroxy gas enrichment resulted in improvement in performance of the engine. Exhaust gas temperature increased due to high flammability and hence Nox will increased. Indicated thermal efficiency increased by 13.28% compared with baseline diesel fuel. Indicated power increased by 6% compared with baseline diesel fuel.

Dahake et al[31]. In their experiment, to assist the poor ignition characteristics of diesel, the HHO gas was be used to improve combustion. When the hydroxy gas is enriched with air in diesel engine, the thermal efficiency for compression ratio 18 increases by 9.25% comparing to baseline diesel combustion and the specific fuel consumption was reduced by 15% at full load condition. The HC emission was reduced at an average of 33% due to better combustion at higher compression ratio with hydroxy gas. The CO emission was reduced marginally, an average of 23% reduction of CO emission was observed. NO was increased with hydroxy gas enrichment at full load condition. The exhaust gas temperature was also increased. Smoke opacity was 8% as compared 10% for baseline diesel operation was observed

Bhavesh et al [32] This paper presents the concern with the HHO gas addition on performance and combustion characteristics of a Constant speed CI engine with variable compression ratio and variable load. The

results are shown on the graphs of CI engine for the brake thermal efficiency, indicated thermal efficiency, mechanical efficiency and fuel consumption with the use of HHO for varying compression ratio and load.

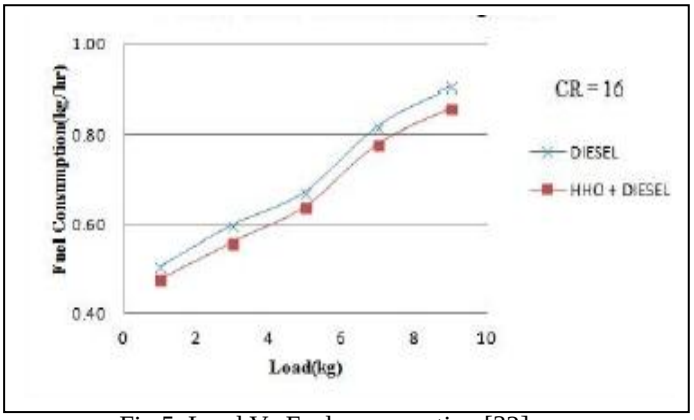

Fig 5. Load Vs Fuel consumption [32]

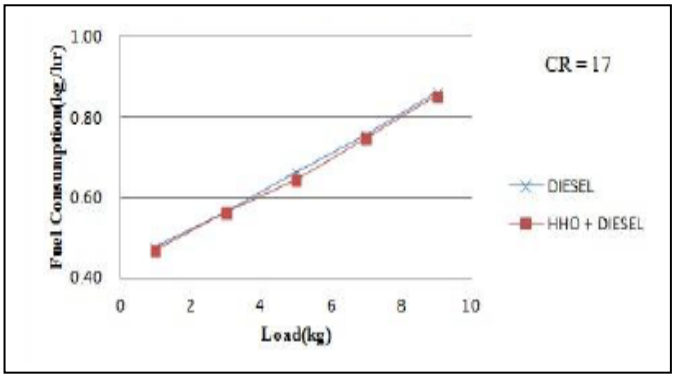

Fig 6. Load Vs fuel consumption [32]

Naveen et al [33] A conventional 4 cylinder SI engine was adapted to operate on gaseous hydrogen. Compressed gas at 200 bars in steel bottles was introduced to the engine by external mixing. The first stage regulator drops the pressure to 3 bars to a copper gas supply line where a flow meter is installed. The second stage regulator supplies hydrogen to the mixing apparatus installed on the inlet manifold. Spray nozzles for water induction are placed approximately 4 cm away from the inlet valves. Ignition timing was set to 10° before TDC and fixed. First tests were performed with the mixer installed on top of the carburetor body. This is the usual configuration in propane mixing. Serious backfire was observed with this installation. Another mixer was then put between the carburetor body and inlet manifold. Backfire was prevented in this option. Under no-load condition, the engine operated flawless with a smooth idling. When load is applied and engine speed is below 2600 RPM, serious backfire occurred and caused a sudden drop in engine power. Water mist from the spray nozzles greatly enhances the backfire-safe operation. Specific features of the use of hydrogen as an engine fuel were analyzed. Results of the tests demonstrated that there will be power loss for the low speed operation whereas high speed characteristics could compete with gasoline performance. The increase in thermal efficiency was obvious. It has been proved that

hydrogen is a very bright candidate as an engine fuel. No_x emissions were about 10 times lower than with gasoline operation. CO and HC emissions were almost negligible as expected. Traces of these emissions were present because of the evaporating and burning lubricating oil film on the cylinder walls. Combustion properties of hydrogen favor fast burning conditions such as in a high speed engine. Design changes that would allow the engine to greater speeds would have a beneficial effect. Appropriate changes in the combustion chamber together with better cooling of the valve mechanism, would increase the possibility of using hydrogen across a wider operating range. Sequential injection of gaseous hydrogen instead of carburation could greatly solve the backfire problem. Better performance could be obtained. Even further, liquid hydrogen either internally mixed or injected into the manifold could be a measure against backfire due to its extraordinary cooling effect (20 K temperature). An electronic control unit that measures the speed, and varies the injection timing together with ignition timing installed on a supercharged, intercooled, high compression ratio, short stroke and high speed engine seems to be the most appropriate way to get the best from hydrogen's unique properties. Hydrogen has the potential to achieve problem-free operation in IC engines. The future advances depend on whether hydrogen can be obtained abundantly and economically. consumption reduced by 8.7% compared with baseline diesel fuel. Exhaust temperature increased by 4% compared with baseline diesel fuel.

Durairaj et al [34] The work focus on the production, characteristics of bio diesel and how it can be aided with oxy-hydrogen gas pre-heated with the help of waste heat recovered from automobile exhaust .This process reduces the emissions of unburnt hydrocarbons, carbon monoxide and particulates and also the thermal efficiency is increased by pre-heating. In this work the biodiesel is produced by the process called trans esterification (reaction of fat with alcohol to form esters and glycerol).Oxyhdrogen gas is produced by electrolysis with an appropriate alt as a solvent. Potassium hydroxide is used as the catalyst .The electrodes used is stainless steel. Preheating is done to the HHO gas using the recuperators, it consists of hot copper tubes and the heat from those is transferred to the gas through convectional heat transfer. In this work biodiesel is used without blending it and with 10%,20%.30% blend with diesel along with this HHO gas from recuperator is passed to the inlet manifold of engine cylinder. Lean mixture ratio combustion in IC engines had the potential of producing low emissions and higher thermal efficiency, unburnt hydrocarbons and unburnt fuels, formation of carbon monoxide, emission of NOx are reduced.

Turan et al [35] The goal of this work is to run a conventional diesel enriched engine with HHO-CNG mixture without making any modification. The effects of HHO and HHOCNG fuels relative to neat diesel operation were investigated in between 1200 and 2600 rpm engine speed and the efficiency parameters as well as emission parameters are resulted. A no modified, 4stroke, 4cylinder, water cooled, direct injection diesel engine was used for the experiment .CNG is transferred to HHO towards mixing chamber before intake manifold. The amount is measured using flow meters. HHO/CNG addition increased the torque. Efficient combustion, less fuel consumption.2.7% and 4.75% brake torque improvement .At low speeds the substitution of diesel fuel causes lean burning and more intake CNG & HHO fuels, Stable engine performance, reduced exhaust temperature, Increased parameters and reduced exhaust emissions, increased BSF, fuel economy.

Zammit et al [36] The objective of this work includes the study of emission gases using hydrogen. The main drawback of this technology is to find the power input to produce hydrogen. The hydrogen gas is produced by electrolysis of distilled water using sodium hydroxide. The hydrogen gas produced by electrolysis is fed to inlet manifold at various engine speeds and at normal loads .Adding a small amount of hydrogen to the intake of engine increased the performance of the engine, diesel engine utilizes high pressure, common rail direct injection that improves air-fuel ratio mixing and combustion efficiency considerably. Hence the results obtained are much smaller .And also using of turbocharger and EGR in diesel engines diluted and dampened the effects of hydrogen, at certain combinations of air-fuel mixture, the addition of hydrogen increased the HC emission, increased power output with hydrogen oxygen addition have been observed and it was more significant in petrol engines, hydrogen addition produced best effects at lean mixture operation and retarded timing. And at these conditions the increase in power output was more than the power needed to generate hydrogen, from the results we can conclude that the addition of hydrogen is most beneficial if the air-fuel ration is optimized, HEC could also be used in lean burn CNG and LPG in SI engines in an effort to make these engines even more sustainable while using worldwide.

Kale et al [37] The goal of this work is the comprehensive review on the performance and emission of CI engine using HHO and biodiesel as alternate fuel or supplement to diesel fuel. HHO has outstanding advantages compared to other alternative fuels since it is carbon free fuel which results in total elimination of HC, CO and CO2 emissions. It's a nontoxic, no odorant gas and can burn completely. The optimum hydrogen flow rate was 7.5 LPM. Time of injection was 5 before TDC and 40 after TDC. Increased efficiency parameters ,the brake thermal efficiency increased by 2.6% at 19kw,brake specific fuel consumption reduced by 7.3%,torque increased by 19.1%,13.5% reduction in CO and HC emission, complete combustion as HHO gains more flame speed , NOx increased by 13% while using HHO in diesel engines, use of HHO and biodiesel combination leads to increased efficiency parameters. However increase in NOx emission cannot be prevented.

Zammit . Et al[38] . The aim of this work was to investigate the effects of hydrogen addition in engine air intake on performance and exhaust emissions. Addition of HHO is most effective in stabilizing and enhancing the combustion of lean air-fuel mixture inside the petrol injected engine, allowing for lower HC,CO and CO_2 emissions. The test was carried using dynamometer loading on three types of engines 1) carbureted petrol engine 2)fuel injected petrol engine 3) diesel engine. The HHO was produced using electrolysis of distilled water using sodium hydroxide using two different electrolyzer designs. Using hydrogen combustion enhancement to stabilize lean petrol engine operation would also a low for higher compression ratios because hydrogen suppresses engine knock while lean mixtures are more resilient to knocking. Addition of hydrogen increased the temperature in cylinder and this temperature promotes oxidation of HC and CO. Increased output power in petrol engine but the results are not significant in diesel engines due to effect injection system and also CI combustion takes place spontaneously at various locations ,in most of the cases the increase in output power was not enough to produce hydrogen even if a 75% efficient generator was used, for a diesel engine running at 1500rpm,the efficiency at 75% of full load increased from 21.6% to 25.6%,hydrogen also reduces the quenching distance inside the cylinder and therefore lesser HCs are emitted because emission of HC depends on quenching distance. The hydrogen addition produced best effects at lean mixture operation and retarded spark timing.

Tuan et al [39] This work mainly describes the simulation study on the impacts of HHO gas mixture addition with the support of AVL booster. The engine used is 4cylinder SI engine which has a CC of 100.and the engine speed was 3000rpm.The HC formation are due to:1)fuel vapour is absorbed into oil layer and deposits on the cylinder wall during intake and compression.2)Partial burning or complete misfire. The simulation study is carried in different models:1)simulation model :the simulation tool used is AVL boost v 2009,1 2)NO_x formation model 3)CO formation model 4)HC formation model 5)heat transfer model . NO_x emission gradually increases especially at lean mixtures .NO_x emission mainly depends on temperature of combustion. and hydrogen has got high combustion temperature. The BSFC was saved about 13% to 19% when 2l/min to 6l/min HHO was added.

Shivaprasad et al[40] This article experimentally investigated the performance and emission characteristics of a high speed single cylinder SI engine operating with different hydrogen gasoline blends. For this purpose the conventional carbureted high speed SI engine was modified into an electronically controllable engine with help of electronic control unit (ECU) which dedicatedly used to control the injection timings and injection durations of gasoline. Various hydrogen enrichment levels were selected to investigate the effect of hydrogen addition on engine brake mean effective pressure (Bmep), brake thermal efficiency, volumetric efficiency and emission characteristics. The test results demonstrated that combustion performances, fuel consumption and brake mean effective pressure were eased with hydrogen enrichment. The experimental results also showed that the brake thermal efficiency was higher than that for the pure gasoline operation. Moreover, HC and CO emissions were all reduced after hydrogen enrichment. Based on the experiment the following results were obtained. The addition of hydrogen helps in improving Bmep. The maximum Bmep obtained at 20% blend of hydrogen for an engine operating at 3000 rpm speed. The addition of hydrogen is effective on improving engine brake thermal efficiency. An increase of brake thermal efficiency was observed till a hydrogen fraction of 20%. Beyond this, the brake thermal efficiency is declined due to reduction in air quantity. The volumetric efficiency decreases as the percentage of hydrogen increases as hydrogen tends to replace air from the mixture. HC and CO emissions reduce with the increase in percentage of hydrogen mainly due to increase in the cylinder.

Yadav Milind S. et al.[41]This experiment shows the increase in the performance characteristics due to addition of HHO gas in a diesel engine. Fuel consumption, Brake thermal efficiency, volumetric efficiency and load are the parameters which were kept under observation during the tests. The results show a decrease in specific fuel consumption. At the maximum load of 8 kg of load during testing, almost 10 g of less fuel is required to produce same power hour. Increase in the volumetric efficiency is because more volume of the mixture is entering inside the combustion chamber with respect to engine swept volume when the blended fuel is sent inside the combustion chamber. There is also an increase in brake power due to presence of hydrogen gas. An interesting result has been found out that due to the presence of water vapour inside the combustion chamber, the temperature inside decreases which helps preventing knocking and formation of carbon deposits on the walls of the cylinder.

3. Conclusion

The addition of HHO gas in internal combustion engine improved the brake power of the engine. This should be due to the hydrogen present in HHO gas. The increase in the brake power can be ranged from 5.07% to 11.5%. An increase in brake thermal efficiency has been observed in all cases. This can be accounted by the presence of hydrogen in HHO gas which has a high calorific value which is much higher than that of fossil fuels. There was a net decrease in specific fuel consumption by the engine. This has been accounted by the much higher burning capacity of fuel when HHO gas is added. This is due to the combined effect of hydrogen and oxygen which helps in achieving complete combustion. There was a net decrease in emission of Carbon dioxide, Carbon monoxide, and unburnt hydrocarbons present in the exhaust gas. Fluctuating results are found in case of NOx emission. In several cases, an increase in NO_x emissions was found and in some other cases there was a decrease in NO_x emission. The best electrolyte which was used for production of HHO gas was found out to be KOH at an average concentration of 6 gram/litre.

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