An Overview of the Effect of using HHO on Spark Ignition and Direct Injection Engines Combustion, Performances, and Emissions Characteristics

Hagar Alm-Eldin Bastawissi[1], E. A. El Shenawy[2], Medhat Elkelawy[3], Osama Hendawy [4]

[1] Mechanical Power Engineering Departments, Faculty of Engineering, Tanta University, Tanta, Egypt – email: hagaralmeldin@f-eng.tanta.edu.eg
[2] Mechanical Power Eng. Departments, Faculty of Engineering, Tanta University, Tanta, Egypt – email: el-shinawi.abdulhamid@f-eng.tanta.edu.eg
[3] Mechanical Power Engineering Departments, Faculty of Engineering, Tanta University, Tanta, Egypt – email: medhatelkelawy@f-eng.tanta.edu.eg
[4]Mechanical Power Engineering Departments, Faculty of Engineering, Tanta University, Tanta, Egypt– email: henawiosama@yahoo.om

Abstract: One of the major issues, the energy crisis, makes the globe dangerous and violent [1]. Every day, there is an increase in energy demand. Resources of energy are running out swiftly, and all indicators point to their impending demise. In such cases, renewable energy sources must be given more consideration. The widespread use of fossil fuels renders them unsustainable because they increase CO_2 levels and emit greenhouse gases that harm the environment [2]. With several trials of usage of HHO gas or compressed natural gas as a fuel performance improver on both internal combustion engines powered by gasoline or diesel up until this point, many advancements have been made in this field[3]. This paper comprises a survey of the numerous advancements that have occurred in this area. There was a net lead to an amplified in brake power from 2.1% to 5.8% and an increase in brake thermal efficiency from 10.27% to 35% with the addition of HHO gas. The usage of traditional fuels decreased by 20% to 30%, and HC and CO exhaust emissions decreased by an average of 14% and 18%, respectively.

Keywords: HHO Electrolysis, hydrogen production, IC engine, Performance, and emission

I. Introduction

Internal combustion engine vehicles will become less common over the coming decades and eventually go out of production[4, 5], although research and development will keep going in the interim to make them more cost-effective and environmentally [6-8]. Shortly, it is anticipated [9] that both the detrimental effects of greenhouse gas emissions on the environment and our reliance on fossil fuels decrease [10-13].

These days, researchers study the usage of alternative fuels in internal combustion engines such as biodiesel and bioethanol, and hydrogen as a blended additional fuel in order to improve the engine performance and emissions [14-17]. The results obtained from this research show that the using of alternative fuel additives might be used as combustion enhancers for the application of internal combustion engines. The produced biofuel is optimized and the necessary characteristics have been measured [18-20]. However, the engine emissions and combustion process were experimentally tested at different engine speed and load conditions [21, 22].

The most popular method of combining hydrogen is through the HHO system's electrolysis of clean water [4, 23]. To begin the ionization reaction and enable the separation of pure water into ions, a solution comprising KOH, NaOH, or NaCl electrolytes in various quantities is created. The HHO that develops from the electrolysis of pure water has a molar ratio of 33.33% oxygen to 66.66% hydrogen. This gas has been referred to by a variety of names in the literature, including HHO gas, Brown's gas, hydroxy gas, Oxyhydrogen and, water electrolysis gas, hydrogen, water gas, Oxy-hydrogen fuel, hydroxyl gas, and even H2+O2[24]. It is recommended to use HOH in internal combustion engines for many reasons as follows:

- Hydrogen is an excellent energy source, with 33% oxygen present for increased combustion, and requires little to no maintenance.
- It has been scientifically shown that hydrogen can be used for transportation and that it has the highest mass-based heating value of any chemical fuel [3].
- Additionally, it is environmentally friendly and regenerative.
- Enhances performance rates and lowers exhaust emissions by enhancing fuel combustion efficiency[3].

We have realized the need for a new sustainable fuel that does not pollute the environment as a result of the excessive possible result [25, 26]. A novel solution resulting from this study is the use of HOH as a fuel improver in internal combustion spark engines that use fossil fuels as their primary source of combustion. Electrolysis produces brown gas, also referred to as HHO gas or a mixture of oxygen and hydrogen. When HHO gases are ignited, they will burn, releasing heat energy and water vapor as byproducts [13, 27, 28]. In the case of enhancing the combustion process with HHO gas, an engine can provide more brake force while emitting fewer toxic emissions. The components of HHO gas are oxygen and hydrogen [23, 29]. Although hydrogen is an intriguing and well-known fuel for internal combustion engines, there are still numerous obstacles to be solved. This is the most serious issue in the production and storage of hydrogen. With safety and at a reasonable price because of the high-energy needs, the requirement for specialty materials, and the adverse impacts of the usage of hydrogen in some engine parts were avoided [30, 31].

Hydrogen may be generated from a variety of sources, including biomass water, various industrial waste compounds, and fossil fuels [27, 32]. One of them, water electrolysis, is regarded as a straightforward and affordable method for getting the required amount of gas; it accounts for roughly 45% of global output. The process of electrolysis can be carried out using electrical energy drawn from a battery or the engine's alternator [33]. The resultant gas is referred to as HHO, oxy hydrogen gas, brown gas, etc. There is a ton of evidence in the public domain about how on-demand hydrogen affects fuel economy. One of the most advantages of hydrogen, in comparison to practically all other fuels, hydrogen has a wide range of flammability [34]. Oxygen reduces the number of unburned hydrocarbons by encouraging more fuel molecules to participate in combustion [35]. The earlier study that was done by scientists in various domains is connected to the research and helped one obtain a foundation for this work, which is presented in this paper.

II. EFFECT OF HHO ON SPARK-IGNITION ENGINE

The effects of HHO addition to gasoline in a spark engine were looked into by Chetan et al. [36]. Regarding the emission analysis test, some intriguing results have been drawn. It was discovered that carbon dioxide and nitrogen oxide emissions are rising. The amount of carbon monoxide and unburned hydrocarbons released, on the other hand, decreased. This has been put to the test using various types of gasoline, as shown in figure 1 and figure 2.

A 4-stroke SI engine was used in an experiment by Dhananjay et[36] with HHO gas added to gasoline fuel. Interesting findings that have been listed out had been formed. HHO use in gasoline engines improved combustion efficiency, which led to a 20% reduction in fuel consumption. The using of HHO in gasoline engines has a major effect on hazardous emissions like carbon monoxide and unburned hydrocarbons and frequently gains less emission. The power output of a gasoline engine increased by 5.71% when HHO was used in the engine by about 5%. However, more thermal efficiency was achieved. The graphs displayed illustrate the increased in thermal efficiency and decreased SFC, consider figure 3 and figure 4.

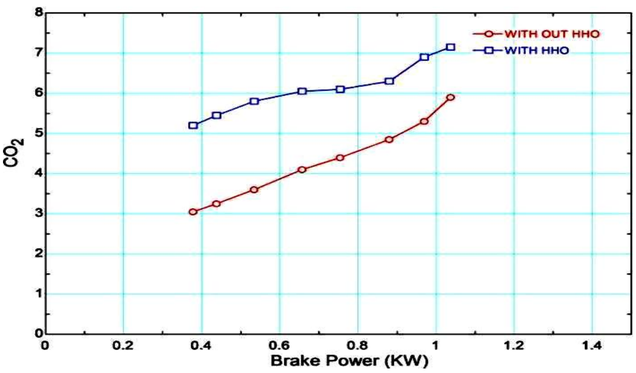

Fig. 1. CO2 Concentration Variation with Load [36]

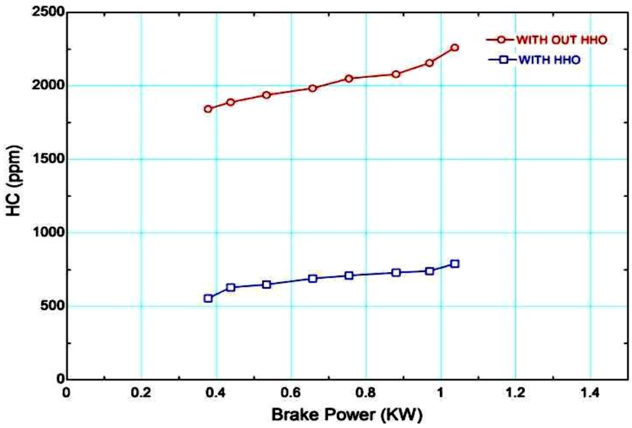

Fig. 2. HC Concentration Variation with Load [36]

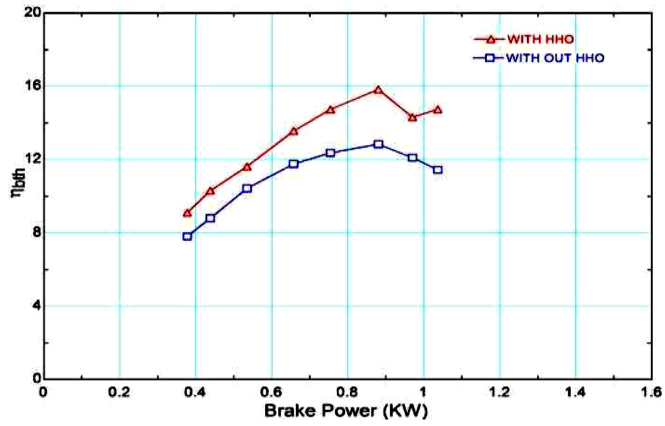

Fig. 3. Thermal Efficiency and brake power [36]

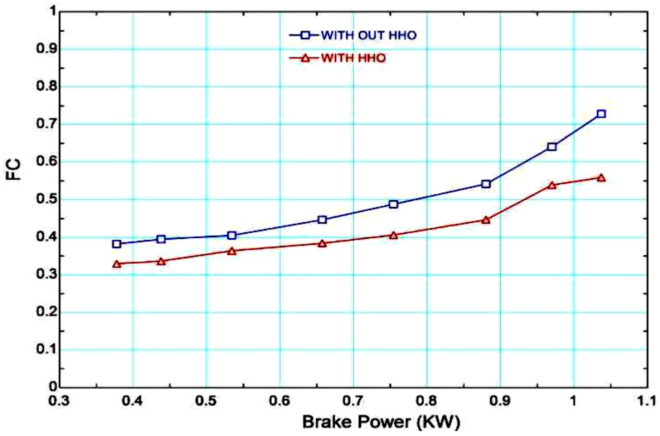

Fig. 4. Variation of Fuel consumption with brake power [36]

According to Pranay et al. [36], the electrolysis of vary Fig. 4. Thermal efficiency variation with loads [36]. Electrolytes produce hydroxy gas (HHO) (hydrogen generator). A four-cylinder, four-stroke, and spark ignition (SI) engine was run on oxygen as supplemental fuel with no modifications. Investigations were conducted into how it affected engine performance parameters and exhaust pollutants. Since HHO's lower heating value is extremely high in comparison to that of gasoline, running with HHO resulted in a net change in specific fuel consumption of roughly 20 to 30%. Due to the lubricating oil vaporizing during HHO operation, traces of HC emissions were observed.

Experiment with the engine's performance, combustion, and exhaust characteristics. powered by natural gas and augmented with 0%, 5%, 10%, 15%, and 20% hydrogen was carried out by Sandhu [37]. The following is a summary of the main findings: For the engine to run smoothly, the electronic fuel injection timed manifold injection was quite useful. As the proportion of hydrogen increases, so does the BTE. The slimmer area has a greater increase in BTE. As the proportion of hydrogen increased, the emissions of CO and HC dropped. The rise in NOx emissions was caused by the rising hydrogen content.

At lean combustion, NOx levels are very low. The goal of low CO and NOx cannot be achieved because CNG has a lower burn speed and a high combustion energy, both of which reduce the engine's ability to burn leanly. Because of its unfavorable characteristics and the associated concern, using plain hydrogen lease for IC engines now appears to be a long-term proposition. The addition of hydrogen to CNG can significantly improve the lean burn limit and the trade-off between HC, CO, and NOx emissions.

Mohamed's [38] The use of HHO gas in the IC engine when mixed with gasoline attracted notice. They observed that 6 g/L of KOH as a catalyst delivers improved efficiency at various speeds of the engine after using two different types of electrolytes for the electrolysis process. Additionally, they discovered that at various engine speeds, 4 g/L of NaOH provides superior thermal efficiency compared to other NaOH concentrations. The following outcomes were obtained when HHO gas was used in conventional engines: When HHO gas was introduced to the air/fuel mixture, the engine's thermal efficiency rose by 10%, resulting in a 34% decrease in fuel consumption. When HHO is added to the engine, the average concentrations of CO, NOx, and HC gases are lowered to about 18%, 15%, and 14%, respectively. KOH, with a concentration of 6 grams per liter, was discovered to be the best available catalyst.

Sharma et al.[39] looked into how adding hydroxyl gas affected various engine performance traits in a four-stroke, multi-cylinder spark ignition engine. These experiments produced results. On average, the engine's braking power has increased by about 11.6%. Motor fuel consumption has been reduced by around 6.36% on overall. The engine's braking thermal efficiency has risen by about 10.27% on general. The engine's exhaust gas temperature has lowered by about 4.1% It was brought about by enhanced fuel combustion, which also results in a notable decrease in NOX emissions from the exhaust gas.

Brown gas produced by water electrolysis was added to a gasoline engine to improve performance, according to Bhardwaj et al[40]. The following results were drawn based on an experimental study. It was noted that HOH and gasoline could be combined safely. When gasoline and brown gas are combined, significant results are obtained. Due to a reduced volumetric heating value, a reduction in power output was noted. Indicated the ratio of B.P. to F.P. increased, which boosted thermal efficiency. Due to an increase in flame burn Speed, spark retardation, or the best possible timing for the spark was used. The combustion delay and the length of combustion lengthen as the A/F ratio rises. It was discovered that direct substitution of hydrogen for carbon-based fuel resulted in a decrease in CO2, CO, and HC. At high engine loads, the amounts of CO2 and HC in the exhaust increased as the hydrogen proportion increased.

To figure out the effect of HHO gas on engine emission parameters, Musmar et al [41] conducted experimental studies. A fresh air mixture was added to the HHO gas right before it entered the carburetor. A sample of exhaust was taken using a gas analyzer, and the constituents of the exhaust were identified and their concentrations were determined. The results show that using a combination of air, HHO, and fuel reduced nitrogen oxides (NOX) and nitrogen monoxide (NO) by nearly 50%. Additionally, the carbon monoxide level had dropped to roughly 20%. Additionally, there had been a 20% to 30% decrease in gasoline use.

The emission and performance characteristics of conventional gasoline and HHO gas were studied by Prasad et al.[42] on a single-cylinder, four-stroke SI engine without any alterations or storage tanks. Their main conclusion was an average 6.7% reduction in HC emissions when compared to operations using only gasoline. With the introduction of hydroxyl gas in the case of gasoline, thermal efficiency rises even in the absence of load changes. By employing the HHO technique, S.F.C. gains on average by 16.3%. When compared to operations using only gasoline, HC emissions are reduced on average by 6.7%.

Petrol, LPG, and HHO fuels were used in an experiment by Dabur et al. [43] and were compared on the platform. Following the comparison, the outcomes are as follows: Brake force, mechanical effectiveness, indicated power, and characteristics of knocking, it improved engine performance. The 110cc maestro's highest brake thermal efficiency is noted. Fuel yields 55%, LPG yields 62%, and HHO yields 51.7%. Increases in additives result in a decrease in carbon monoxide, unused oxygen, and hydrocarbon smoke, along with an increase in brake thermal efficiency. For HHO fuel, the lowest CO2 and NOX emissions were found. The mechanical efficiency against a load of HHO fuel is the highest (78%), followed by LPG (72%), and gasoline (63.8%).

The addition of HHO gas to a petrol engine was the main focus of Mahesh Kumar's study[44]. Hydrogen utilization improved the combustion efficiency of gasoline engines, which led to a 20% decrease in the consumption of fuel. By using hydrogen in gasoline engines, hazardous emissions like carbon monoxide and unburned hydrocarbons are emitted less frequently. When hydrogen is used in gasoline engines, the output power of the engine is raised by about 5.72%, and the thermal efficiency is increased by about 5.1%. After studying the fundamental characteristics of the gas produced by the electrolysis of water, Aaditya et a[40] By combining it with air, it was used in a motorcycle as a fuel alternative for gasoline. High grades stainless steel was used to construct the HHO reactor, while NaOH was used as the electrolyte. They stated that the bike's mileage had increased by 30 to 60% and that the amount of pollution in the exhaust fumes had decreased.

Seralathan et al. [45] discussed raising the conventional motorcycle's speed while maintaining relevant performance considerations. A 223cc, 17-horsepower n engine with such a maximum velocity of 125 kmph was chosen. The arrangement included an HHO gas generator, and the results were achieved by chaining gear ratios. The traditional motorcycle has been modified, which has improved the vehicle's performance. The altered gear ratios caused the vehicle's speed to raise to 170 km/h. better gas mileage and fewer emissions are provided by the car.

A TVS Victor 109cc engine's HHO gas addition was tested by Abhishek et al. [46]. With a cleaner and quieter engine, more miles per gallon, more horsepower, and lower emissions were all achieved. This paper's theoretical calculations used to calculate the HHO emission were its main focus. According to these estimates, the electrolysis water gives 0.063 liters of oxygen gas and 0.25 liters of hydrogen gas for a current of 4.5 amps during a time of 216.5 seconds.

The performance of the Dry cell HHO gas producer was customized by Bambang et al [47] by utilizing the duty cycle of pulse width modulation (PWM). HHO gas was produced and then tested to a 2-cylinder, 650 cc Sinjai petrol engine with port injection and a venturi. Duty cycle PWM variations for the HHO gas generator are 20%, 40%, 60%, 80%, and 100% (or the same as non-PWM). Calculated performance metrics include the HHO generator's temperature, efficiency, and specific energy input. A venture mechanism located on the combustion air inlet duct is utilized to produce hydroxyl gas, which is subsequently used as a fuel mixture in the Sinai engine. Additionally, the metrics of power, torque, BMEP, thermal efficiency, specific fuel consumption, and Thermal efficiency is investigated to assess the influence of HHO gas addition on the performance of the Sinai engine. The results demonstrate that the optimum HHO gas generator performance is produced by a PWM system with a 40% duty cycle and characteristics such as a specific energy input of 33,122 MJ/kg, generator efficiency of 20,065%, and generator temperature maintained below 600 °C. Use of the aforementioned HHO gas generator on normal ignition timing in terms of power, torque, BMEP, and thermal efficiency, The Sinai engine generates a 2.76%, 2.27%, and 3.05% increase, respectively, and a 7.76% decrease in BSFC. Retarded ignition timing is replaced with MBT, which can improve performance such as power, torque, and thermal efficiency, by 7.65%, 6.55%, and 15,50%, while BSFC is reduced by 22,06%

HHO gas was employed by Gowtham et al. [48] as an additive fuel for a 153 cc internal combustion engine. These outcomes were achieved. The bike's actual fuel economy is 39.4 km/l under typical fuel and air intake circumstances. The bike's mileage is 50.6 km/l when HOH gas is initiated to the intake of air. This results in a huge difference of 11.2 km/l, which increasing the efficiency by 25 to 26%. Their research mainly concentrated on a single-cylinder, four-stroke engine's particular fuel consumption.

The impact of HHO gas on emissions in petrol engines was examined by Tiwari et al. [49]. Analyses of the performance and emissions of petrol engines are done using petrol and petrol with HHO, respectively. Following the completion of the tests with gasoline on the decreasing fuel consumption in gasoline with HHO and gasoline, respectively, the performance and emission analysis findings are compared and come to the following conclusions. The output power of a gasoline engine is increased by around 5.71% when HHO is used. The HHO gas kit is inexpensive to build and is simple to connect with current engines. Around 5% more thermal efficiency is gained.

III. EFFECT OF HHO ON COMPRESSION IGNITION ENGINE

In a study by Dahake et al. [50], It was discovered that employing HHO gas to enhance combustion might improve diesel's poor ignitability. When hydroxy gas is supplemented with air in a compression ignition engine, the thermodynamic performance for higher compression 18 increases by 9.26%, and the specific consumption of fuel decreases by 15.2% at full load. The HC emission was reduced by a mean of 33% as a result of improved combustion at higher compression ratios using hydroxy gas. An average 23% reduction in CO output was seen, which is a modest decrease. At full load, NO was elevated by hydroxy gas enrichment. Additionally, the temperature of the exhaust gases rose. In comparison to baseline diesel operation, there was 8% less smoke opacity.

A one-cylinder diesel engine was used to test the HHO kit by Rahul R. Shitoleet al. [40]. Along with input air, hydroxyl (HHO) gas is fed to the engine. H2 and O2 are separated from the water using a hydrogen generator. After passing via safety mechanisms, this separated HHO is subsequently given to the engine. According to the results on the single-cylinder, four-stroke compression ignition engine, the hydroxyl gas enrichment improved the engine's performance. Due to the high flammability, exhaust gas temperature increased, which led to a rise in NOx. Comparing indicated thermal efficiency to baseline diesel fuel, it rosed by 13.29% in comparing to base diesel fuel, indicated power raised by 6.1%.

The emissions and performance of CI engines using hydroxyl and biodiesel such as an alternative fuel or supplement to diesel fuel were thoroughly reviewed by Kale et al. in their study[51]. HHO has exceptional benefits over other alternative fuels since it is carbon-free, which eliminates CO, HC, and CO2 emissions. It is a combustible gas that is harmless and has no odor. The hydrogen flow rate that worked best was 7.5 LPM. The injection occurred 40 after TDC and 5 before TDC. Increased efficiency parameters include an increase in brake thermal efficiency of 2.61% at 19kw, a 7.31% reduction in brake-specific fuel consumption an increase in torque of 19.1%, a reduction in HC and CO emissions of 13.5%, complete combustion as HHO increases flame speed, an increase in NOx of 13% when using HHO in compression ignition engines, and an increase in efficiency parameters when using HHO and biodiesel together. However, there is no way to stop NOx emission growth.

Without making any modifications, Turan et al. [40] operate a normal diesel-enhanced engine powered by an HHO-CNG combination The impacts of HHO and HHOCNG fuels were evaluated between 1200 and 2600 rpm engine speeds, and the efficiency metrics, as well as emission characteristics, are the outcomes. A 4-stroke, 4-cylinder, water-cooled, direct-injection diesel engine was used in the experiment. CNG is transported from HHO to the mixing chamber before to the intake manifold. Utilizing flow meters, the quantity is determined. The torque was boosted by adding HHO/CNG. Less fuel is consumed due to efficient combustion. Improvements in brake torque of 2.71% and 4.76%. At low speeds, replacing diesel fuel with CNG or HHO results in leaner combustion and increased fuel intake. Engine stability decreased exhaust temperature, enhanced parameters, decreased exhaust emissions, increased BSF, and boosted fuel efficiency.

In a single-cylinder compression ignition engine, Naseeb Kahn et al. [52] utilized B20 as the pilot fuel and supplied hydrogen at a rate of 15 liters per minute. They then compared brake-specific fuel consumption, the brake thermal efficiency, and Nox emission different injection opening pressure. Break thermal efficiency was increased by 33 percent. Maximum and minimum brake thermal efficiency are indicated at 220 bars injection opening pressure (IOP) and 200 bars, respectively (IOP) When hydrogen is added to the pilot fuel at a rate of 15 liters per minute, the consumption of brake-specific fuel is decreased to 37.1%. At 200 Bars IOP, there is minimal fuel use for the brakes. Except for NOx, exhaust gas levels have decreased.

The formation of HHO gas in the presence of various electrolytes, including NaOH, KOH, and NaCl, was the main emphasis of Ali et al. [53]. Both gasoline and diesel engines underwent the load test, and the results revealed the performance. For spark ignition engines, using the HHO system increases engine torque by, on average, 32.4% when compared to pure gasoline operation. This means that during the studies, an increase in average engine power of 27% in comparison to operating using only gasoline is realized. HHO system use results in an average 19.1% increase in engine torque for diesel engines when compared to pure diesel operation. In SFC, the HHO method produces an average increase of 16.3%. Unless HECU is added to the system, the HHO with gasoline fuel and diesel produced more engine torque at mid- and higher engine speeds than pure gasoline and diesel-fueled engine running. During experiments, the power increase in engines was greater than the electric power used and the less fuel consumption attained with the help of the HHO system combined. This shows how effective the system is.

A 553 cc single-cylinder constant speed Kirloskar engine was used in the experiment by Manu et al. [54]. They outlined their conclusions in light of the experimental findings. With an HHO gas flow rate of 2 LPM and a load of 14.8 kg, the maximum Brake Thermal Efficiency of 34.99% was obtained (38 kW).Higher BTE is a result of better hydrogen and air mixing, which improves combustion. Additionally, hydrogen-enriched engines have exceptional lean-burning capabilities, which raises their thermal efficiency. The overall diesel fuel savings at a load of 5.65 kg and a 2 LPM HHO gas flow rate was 13.23%. HHO gas will partially replace some of the diesel fuel used when it is added, reducing the quantity of diesel used overall. When HHO gas was added, the minimal BSFC, which was 0.255 kg/kWh with diesel fuel, was decreased to 0.235 kg/kWh. It was determined that undesirable emissions such as carbon monoxide and carbon dioxide were reduced, which justifies the use of hydrogen as an environmentally beneficial fuel in future engines.

The performance traits, exhaust emission traits, and combustion process of an engine powered by a hydrogen-diesel blend were compared to an engine powered by diesel fuel by Tayfun et al. [55] . Diesel fuel can be advantageously supplemented with hydrogen to increase engine efficiency and control exhaust emissions. Hydrogen usage reduces NOx and CO emissions. In one experiment, HHO gas was injected through the air filter into the 4-stroke diesel engine's inlet manifold and combustion chamber. They examined the fuel consumption rates with diesel as the major source and with diesel and HHO gas during typical operation. They saw a net reduction in fuel consumption of 12.08%. On one of the occasions during the performance test, the braking power reduction was seen. Increased engine oil life was seen coupled with reduced carbon buildup in the cylinder.

The direct injection diesel engine's performance was examined by Rashad et al. [56] to determine how adding HHO gas to the inlet air might affect it. An experiment was run at a steady speed with a variable load and the amount of HHO created by water electrolysis was added. Utilizing HHO reduced the engine's maximum power. This might be because there is less extra air in the cylinder, which results in a loss of volumetric efficiency, and because the huge volume of Oxyhydrogen in the intake mixture displaces a lot of the intake air. At low loads, the particular fuel consumption reduced (by up to 20%), but at greater loads, there was no discernible decrease. As a result, the experiment's final finding was that the performance of ICES can only be improved at low loads by adding Oxyhydrogen.

The combustion characteristics and performance of a fixed speed, reciprocating engine (CI) with different compression ratio and different load were improved by Bhavesh et al. [57] by adding HHO gas. The findings for the CI engine's braking thermal efficiency indicated thermal efficiency, mechanical efficiency, and fuel consumption when using HHO for variable compression ratio and load are displayed on the graphs in Figure 5.

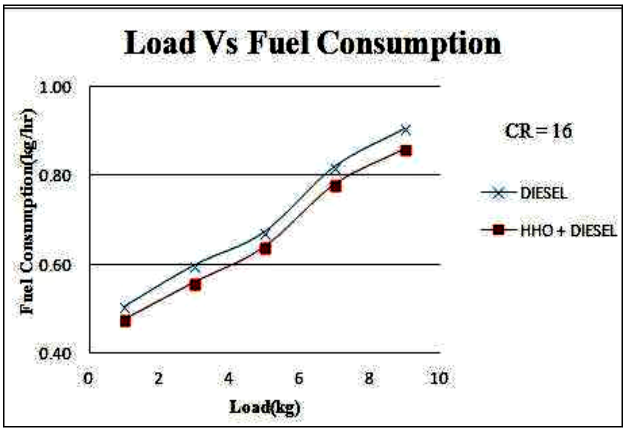

Fig. 5. Variation of fuel consumption with load [57]

The study by Durairaj et al. [50] concentrated on the generation, properties, and utilization of oxy-hydrogen gas that had been pre-heated using waste heat from automotive exhaust. By preheating, this procedure increases thermal efficiency while reducing emissions of carbon monoxide, unburned hydrocarbons, and particulates. In this work, the transesterification method is used to make biodiesel. An acceptable alternative serves as the solvent in the electrolysis process to produce oxygen gas. As a catalyst, potassium hydroxide is utilized. Stainless steel is used for the electrodes. The recuperators are formed of heated copper pipe and use convectional heat transfer to heat the gas, are used to pre-heat the HHO gas. In this work, biodiesel is used with 10%, 20%, and without blending. The recuperator's HHO gas, coupled with a 30% diesel blend, is sent to the engine's cylinder inlet manifold. Lean mixture ratio combustion in IC engines had the potential to result in lower emissions and higher thermal efficiency, as well as lower carbon monoxide production and nitrogen oxide (NOx) emissions and unburned hydrocarbons and fuels.

In an experiment, Yadav Milind et al. [58] discovered that the injection of HHO gas into a diesel engine increased the performance characteristics. The following variables were monitored throughout the tests: volumetric efficiency, fuel consumption, thermal efficiency of brakes, and load. According to the findings, specific fuel usage has decreased. During testing, at the maximum load of 8 kg, nearly 10 g less fuel is needed to provide the same amount of power per hour. The volumetric efficiency has increased as a result of the mixed fuel being fed into the combustion chamber at a higher volume relative to the swept volume of the engine. Due to the presence of hydrogen gas, brake power has also increased. An intriguing finding is that the combustion chamber's temperature falls when water vapor is present, which helps to reduce banging and the buildup of carbon deposits on the cylinder's walls.

IV. CONCLUSION

The internal combustion engine brake power was increased by adding HHO gas. This should be because HHO gas contains hydrogen. The improvement in stopping power can be anything from 5.08% and 11.6%. In every instance, an increase in brake thermal efficiency was seen. The existence of hydrogen in HHO gas, which has a high calorific value that is far higher than that of fossil fuels, can be used to explain this. The engine's specific fuel consumption decreased on the whole. This has been explained by the fuel's much-increased ability to burn when hydroxyl gas is added. This is a result of oxygen and hydrogen working together to achieve complete combustion. Carbon monoxide, carbon dioxide, and unburned hydrocarbons in exhaust gas emissions all decreased by a net amount. When NOx emissions are considered, varying results are discovered. There were some instances where NOx emissions increased, and there were some instances where NOx emissions decreased. KOH at an average concentration of 6 g/l was discovered to be the best electrolyte for the generation of HHO gas.

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NOMENCLATURE

B. P	Brake power
IOP	injection opening pressure
SFC	Specific fuel consumption
BTE	Break Thermal efficiency
IC	Internal combustion
HHO	Hydrogen-Hydrogen-Oxygen
CNG	Compressed natural gas
LPG	liquefied petroleum gas
TDC	Top Dead Centre

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