Utilization of HHO gas with Diesel fuel in stationary compression Ignition Engine

Anil Kumar Dhariwal, Ashish Nayyar, Dinesh Kumar Sharma
Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India
Email- shreemd@yahoo.co.in
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Abstract: **Due to predicted shortage of conventional fuels and their increasing use, there has been a growing interest in alternative fuels like biofuels, methyl alcohol, ethyl alcohol, hydrogen, producer gas, and acetylene, for internal combustion (IC) engine. Gaseous fuels are recommended for clean burning. In the past decades, a lot of research has been conducted on hydrogen-powered and electrically powered vehicles. Hydrogen is being considered as a primary automotive fuel and as a replacement for conventional fuels. Hydrogen has been found to have several properties which are essential to have green alternative fuel to be used in IC engines. Its desirable properties like high auto-ignition temperature, low ignition energy, high flame velocity, high calorific value coupled with its various other combustive properties help in enhancing engine performance and motivate to use Hydrogen in a dual fuel mode in the diesel engine.**

HHO gas (Hydroxy Gas / Brown Gas) generator is a promising technology in the present scenario for using Hydrogen in IC engine, which produces a mixture of hydrogen and oxygen through electrolysis.

In this study, Hydroxy Gas is produced by HHO generation kit (water electrolysis) and injected at the inlet manifold, as a supplementary fuel in a stationary Single Cylinder, Four Stroke, Constant speed, Water Cooled, Direct Injection Compression Ignition Engine. The collected data were analyzed for performance and exhaust emissions of the engine. Results show 9% drop in brake specific fuel consumption (BSFC) and 7% increase in brake thermal efficiency (BTE). The emissions of CO, HC, and smoke have been reduced by 56%, 16%, and 5% respectively for Hydroxy-diesel mixture as compared to diesel alone. A slight increment in NO_x emission of 6% has been noted.

Keywords: hydrogen; hydroxy gas; compression ignition engine.

1. INTRODUCTION

Increasing energy demands, depletion of fossil fuel reserves and growing industrialization with increased pollution have emphasized to explore and use some alternative of conventional petroleum fuels [1]. Global warming is another key factor that motivates to make efforts to reduce emission from the tailpipe of automotive or stationary engines. Performance tests of engine evolution have identified the feasibility of using a range of alternative fuels such as vegetable oil, biodiesel, methanol, ethanol, acetylene, liquefied compressed natural gas, hydrogen, etc.

Among the available alternative fuel options; hydrogen finds a prominent place to replace the present fossil fuels in IC engines. Hydrogen is available abundantly in nature and gives near zero-emissions when used in IC engines. Hydrogen is a long-term, renewable, recyclable and non-polluting. Hydrogen has some positive characteristics compared to Hydrocarbon, the most significant being the absence of Carbon. Very high burning velocity yield rapid combustion and wide flammability. Limit of hydrogen varies from an equivalent ratio ( ) of 0.1-7.1 which helps the engine to operate with a wide range of Air.Fuel ratio. Hydrogen (H_2) as a fuel has an outstanding potential in driving the Global Energy system [2]. H_2 can be derived from various natural resources such as methane, coal, oil shale, and uranium. H_2 can also be produced from electrolysis of water, thermochemical decomposition, and solar photoelectrolysis.

1.1THE PROPERTIES OF HYDROGEN

The comparison of properties of Hydrogen, gasoline, and diesel are as given in Table 1[3]:

Table 1: Properties of Hydrogen, gasoline and diesel fuel

Properties	Diesel	Unleaded Gasoline	Hydrogen
Chemical formula	C_8H_{18}	$C_{12}H_{23}$	H_2
Flame temperature (K)	2600	2473	2318
Flammability limits (volume % in air)	0.7–5	1.4–7.6	4–75
Auto-ignition temperature (K)	453-593	500-753	858
Minimum Ignition Energy (mJ)	---	0.24	0.02
Stoichiometric Air Fuel Ratio on mass basis	14.5	14.6	34.3
Density @ 16ºC and 1.01 bar (kg/m^3)	833-881	721-785	0.084
Quenching distance at NTP (mm)	---	2	0.64
Diffusivity in Air (cm^2/s)	---	0.08	0.63
Net Heating Value (MJ/kg)	42.5	43.9	119.93
Flame velocity (m/s)	0.22–0.25	0.30-.50	2.65– 3.25
Octane number	30	87	130+
Molecular weight (g/mol)	2.015	110	0.2

1.1.1 COMBUSTION PROPERTIES OF HYDROGEN

Combustion properties of hydrogen are presented in Table 1, and illustrated below:

a) Flammability: Hydrogen has a wide flammability range of 4-75% in comparison with all other fuels (For diesel this is 0.7-5% and 1.4-7.6% for Gasoline). As a result, hydrogen can be used in an IC engine over a wide range of fuel-air mixtures.

b) Ignition Energy: It is the amount of energy needed to ignite a combustible vapor or gas mixture. At atmospheric conditions, hydrogen has very low ignition energy. The minimum ignition energy of a hydrogen-air mixture is 0.02 mJ which is lesser than that required for petroleum fuel and enables hydrogen engines to ignite promptly at lean mixtures. However, it poses problems of premature ignition and backfires.

c) Quenching Distance: This parameter measures how hydrogen flames can travel closer to the cylinder wall before they extinguish. Hydrogen has lesser quenching distance (0.64 mm) than petroleum fuel (2.0 mm) which increases the tendency for backfire.

d) Autoignition Temperature: A relatively high autoignition temperature of hydrogen allows the higher compression ratios in an engine, which leads to a higher thermal efficiency. Although, it is not feasible to use hydrogen solely in a compression ignition engine; because the temperature needed for ignition is relatively high.

e) Flame Speed: Hydrogen has higher(faster) flame speed at stoichiometric ratios of nearly 2.65 m/s than of conventional petroleum fuels. Therefore, hydrogen engines can more closely approach thermodynamically ideal engine cycle.

f) Diffusivity: Hydrogen possesses remarkably high diffusivity of 0.61 cm^2/s which helps it to disperse into the air quicker than gasoline. Also, leaking hydrogen is not a pollutant to the environment.

g) Density: Hydrogen has a very low density of 0.082 kg/m^3. This results in two problems of IC engine. Firstly, a very large volume is necessary to store enough hydrogen to provide sufficient driving range. Secondly, it reduces the power output.

h) Air-Fuel Ratio: The stoichiometric or chemically correct air-fuel ratio for the complete combustion of hydrogen in air is about 34:1 by mass which is much higher than the air-fuel ratio required for gasoline or diesel (14.5:1). Being a gaseous fuel at ambient conditions hydrogen displaces more space in of the combustion chamber than a liquid fuel. Hydrogen covers approximately 30% of the combustion chamber, compared to around 1 to 2% for gasoline at stoichiometric conditions. Low ignition energy and a wide flammable range of Hydrogen enable the engine to run on a lean condition which is helpful for the enhanced engine economics and emission performance [4].

Hydrogen is a clean fuel with no carbon emission, as the release of stored chemical energy in H_2 of useful heat produces only water as a product. Hydrogen can be easily produced directly from all primary energy sources, enabling energy for the transportation sector which includes Wind, Solar Power, and Biomass which are all renewable energy sources and thus can be used locally to generate electricity or used as clean fuel for vehicles.

Hydrogen can be used in the liquid state, or in the gaseous state fuel in engines. A cryogenic storage up to a capacity of 20K approximately is required, if it is used in the liquid state. It can also be injected in the gaseous state like liquid petroleum gas (LPG) and compressed natural gas (CNG). Hydrogen also offers the opportunity of running on mixed fuel with gasoline and diesel[5].

1.1 HYDROGEN PRODUCTION

Hydrogen is produced from a wide range of primary resources, employing a wide range of technologies. Despite its abundance occurrence in the universe, it does not occur freely on earth, as it reacts very rapidly with other elements. Therefore, the majority of hydrogen is bound into molecular compounds. The hydrogen can be extracted from higher energy fossil fuels as well as lower energy water. Alternatively, hydrogen can be produced by thermo-chemical water decomposition, photo conversions, photobiological processes, production from biomass, and industrial processes. A detailed review of different processes to produce hydrogen on the industrial level through renewable ways is reported in [6].

1.2 USE OF HYDROGEN IN IC ENGINES

A lot of research has been conducted regarding the use of hydrogen as a fuel in ICEs. In 1820, Reverend Cecil in England was first who planned to use hydrogen as a fuel. Later, Bursanti and Matteucci succeeded the free piston hydrogen engine. Ricardo reported high efficiency when working with hydrogen in IC engine in 1924. In the space program, Hydrogen has been extensively used due to the best energy-to-weight ratio of any fuel and lighter than other fuel[7].

1.3.1 USE OF HYDROGEN IN SPARK-IGNITION ENGINES

As previously reported, Hydrogen has some unique and highly desirable properties, such as low ignition energy, fast flame propagation speed, and wide operational range, those are favorable for fuel in SI engines. Hydrogen fuel operates with ultra-lean combustion that produces low flame temperatures. Which ultimately reduces heat transfer to the walls, improves engine efficiency and NO_x emission.

1.3.2 USE OF HYDROGEN IN COMPRESSION IGNITION ENGINES

Hydrogen cannot be used as a sole fuel in a compression ignition engine due to higher autoignition temperature. Therefore, it is used as an additional/secondary fuel with diesel in CI engines.
Supplementing hydrogen increases Hydrogen to carbon ratio of

the entire fuel and also reduces heterogeneity which leads to more uniform combustion. Conventional diesel engines can be operated on hydrogen–diesel dual mode with up to about 38% of full-load energy exchange without significant loss on the performance parameters.

1.3 COMBUSTION ANOMALIES

Properties of hydrogen such as wide flammability limits, low ignition energy, and high flame speeds lead to abnormal combustion many times. These anomalies include pre-ignition (surface ignition), backfiring, rapid pressure rise and autoignition. The control of abnormal combustion in hydrogen engine is a big challenge for engine design, mixture formation, and load control.

1.4.1 PRE-IGNITION

Pre-ignition is often encountered with hydrogen engines because of the low ignition energy and wide flammability limits of hydrogen. Premature ignition causes the mixture to burn mostly during the compression stroke due to which the temperature in the combustion chamber rises. This temperature rise causes the hot spot formation that leads another earlier pre-ignition in the next cycle. This advancement of the pre-ignition continues until it occurs during the suction stroke and causes backfire. Risk of pre-ignition increases when the hydrogen-air mixtures approach stoichiometric level at higher engine speed and load due to higher gas and component temperatures.

1.4.2 BACKFIRE

Backfire is a significant consequence of the pre-ignition phenomena. When pre-ignition occurs at a point near the inlet valve when the valve is open, the enflamed charge can travel past the valve and into the inlet manifold, resulting in backfire. This becomes dangerous in pre-mixed fuel in engines where it is possible that an ignitable fuel-air mixture is present in the inlet manifold. The occurrence of backfiring is limited to external mixture formation concepts. All measures that help avoid pre-ignition also reduce the risk of backfiring.

1.4.3 AUTO-IGNITION AND KNOCK

Knocking is a common problem reported in hydrogen-fueled engines. When fuel and oxidizer inside the cylinder reach a peak of temperature, then end gas ignites spontaneously without the aid of spark which is termed as auto-ignition. Further, it follows a rapid release of the remaining energy causing high-amplitude pressure waves referred as engine knocking. Engine knocking can cause severe issues such as increased mechanical and thermal stresses. It also depends upon engine design and fuel-air mixtures.

1.4 FUEL DELIVERY SYSTEMS

The mode of fuel induction system plays a critical role in hydrogen operated IC engine. Different fuel induction mechanisms can be grouped into three main types as stated in most of the literature are as:

1. Fuel Carburetion Method,
2. Inlet Manifold and Inlet Port Injection; and
3. Direct Cylinder Injection.

1.5 HYDROXY OR HHO OR BROWN GAS

HHO gas is a combustible gaseous product from electrolyzation of water. It forms when the electric current is passed through water; then it divides into molecules of H2 and O2. This gas is called Hydroxy gas or HHO Gas or Brown gas. **HHO** gas is colorle ss, odorless, and lighter. The flammability of HHO gas is much more than gasoline. The explosion of hydroxy gas is 3 times faster than gasoline. At 1 atmospheric pressure, autoignition of Hydroxy occurs at about 570 °C. At normal temperature and pressure, Hydroxy gas can burn when it is between about 4% to 94% hydrogen by volume and converts to water vapors and releases energy of about 241.38 kJ of energy for every mole of H_2 burned [8].

2.LITERATURE REVIEW

A summarization of previously reported works has been presented in tabular form in Table 2.

S. No	Authors	Test Set Up	Fuel Used	Observation
1	N. Saravanan, G. Nagarajan, K. M. Kalaiselvan, C. Dhanasekaran [9]	four stroke, water cooled, single cylinder, direct-injection (DI) diesel engine	Hydrogen with diesel in dual fuel mode	Usage of hydrogen in dual fuel mode with EGR technique results in reduced smoke level, particulate and NOx emissions.
2	N. Saravanan, G. Nagarajan, G. Sanjay, C. Dhanasekaran, KM. Kalaiselvan [10]	four stroke, water cooled, single cylinder, direct-injection (DI) diesel engine	Hydrogen with diesel -	20% increase in BTE and 13% increase in NOx compared to diesel, whereas Hydrogen-DEE operation resulted in a higher brake thermal efficiency of 30%, with a significant reduction in NOx compared to diesel.

3	C. Pana, A. Megaritis [11]	Ford Puma HSDI diesel engine	Hydrogen and nitrogen with diesel	Efficiency Hydrogen addition resulted in small efficiency reductions at low speed, while at high speed most of the operating points tested showed a slight increase in efficiency. Nitrogen-enriched air reduces the formation of NOx emissions.
4	A. C. Yilmaz, E. Uludamar, K. Aydin [12]	four-cylinder, four-stroke, direct-injection diesel engine	HHO with diesel in dual fuel mode	HHO addition to engine results in increased engine torque and decreased CO, HC and SFC at high speeds.
5	S. A. Musmar, A. A. A. Rousan [13]	Honda G 200 (197 cc single cylinder engine)	Brown gas HHO with diesel in dual fuel mode	50% reduction is noticed in NOx, reduction in CO and fuel consumption was observed by 20% and between 20% and 30% respectively.
6	Fanhua Ma, Y. Wang, H. Liu, Y. Li, J. Wang, S. Zhao [14]	In-line 6 cylinder, spark ignition natural gas engine	variable hydrogen/CNG mixture (HCNG)	With increased hydrogen addition thermal efficiency increased and NOx emission remains unchanged. Unburned hydrogen also decreased with increase of hydrogen addition
7	S. Szwaja, G. Karol [15]	two-cylinder in-line CI F2L511 engine	hydrogen-diesel-air mixture	a small amount of hydrogen when added to a diesel engine shorten the diesel ignition lag, decrease the rate of pressure rise and provide a better condition for the soft run of the engine and can increase engine durability
8	M. Senthil Kumar, A. Ramesh, B. Nagalingam [16]	single cylinder water-cooled direct-injection diesel engine	Hydrogen in vegetable (Jatropha) oil /diesel fueled diesel engine.	Ignition delay, peak pressure and the maximum rate of pressure rise were increased in the dual-fuel mode of operation. Combustion duration was reduced due to higher flame speed of hydrogen
9	T. Tsujimura, S. Mikami, N. Achiha, Y. Tokunaga [17]		Hydrogen jet in constant volume vessel	auto-ignition delay linearly depends on the temperature
10	M. E. Mohamed, Y A. Eldrainy, M. E. Khidr, K. I. Khidr [18]	Skoda Felicia 1.3 GLXi gasoline engine	hydroxyl gas HHO with diesel in dual fuel mode	10% increment in thermal efficiency, 34% reduction in fuel consumption, 14% reduction in HC, 18% reduction in CO, and 15% reduction in NOx.
11	M. Masood, M. M. Ishrat, A. S. Reddy [19]	single cylinder water-cooled direct-injection diesel engine	Hydrogen blend with diesel	highest brake thermal efficiency of 30% at a compression ratio of 24.5
12	C. Pana, N. Negurescua, A. Cernat, C. Nutu, I. Mirica, D. Fuiorescua [20]	D2156 M1N8 type diesel engine	Hydrogen blend with diesel	Results with better energetic and performance of duel fulled (hydrogen -diesel) engine were found due to improvement of combustion process and reduction of carbon content

13	Prithivirajan K, Prakash. E, Sakthivel. M. [21]		Hydrogen blend with diesel	found hydrogen gas suitable for automobile engine while producer gas for stationary engines
14	R. R. Sitole, S. S. Magdum, N. S. Raut, S. Mane, P. B. Borade [22]	single cylinder, four-stroke diesel engine	HHO with diesel in dual fuel mode	Increase in BTE 13.28% and the brake specific fuel consumption reduces by 8.7% at full load condition. Exhaust gas temperature also increases by 4% compared to diesel fuel
15	M. R. Dahake, S.D. Patil, S.E. Patil [23]	single cylinder four stroke diesel engine	HHO with diesel in dual fuel mode	thermal efficiency increased by 9.25% whereas specific fuel consumption, CO and HC reduced by 15%, 33% and 23% respectively

It can be observed from the literature review that addition of Hydrogen or Hydroxy gas with air in diesel engine under duel fuel mode enhanced thermal efficiency and reduced emissions. However, the generation of Hydroxy gas involved typical setup. Thus it presents the motivation for the development of a simple generation kit with existing facilities and to verify the experimental results.

3. EXPERIMENTAL TEST RIG

Experimental test rig consists of a single cylinder, water cooled, four-stroke diesel engine (Kirloskar make, AV1 model) coupled with a hydraulic dynamometer. The test rig was modified by Datacone Engineers Pvt. Ltd., Sangliwadi, India to measure various parameters required to determine the performance of the engine. A gas analyzer and a smoke

Fig. 1: Schematic of the engine test rig meter were used to measure the emission of the engine. The schematic of test rig is shown in Fig. 1.

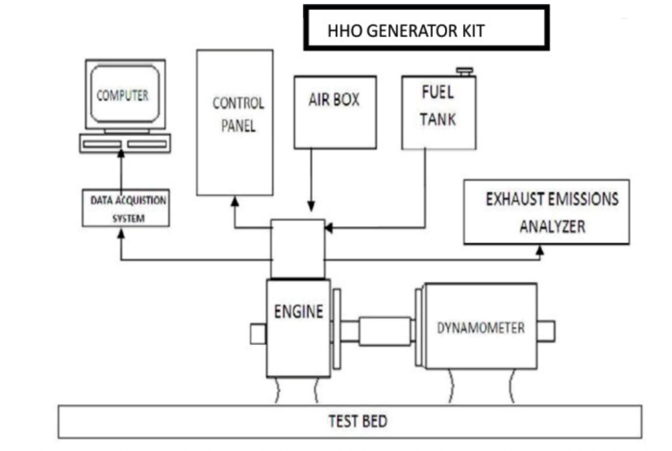


Fig. 1 Engine Test Rig

Table 3 represents the technical specifications of the engine.

Table 3 Technical specifications of the engine

SPECIFICATIONS	DESCRIPTION
Make	Kirloskar
Model	Av1
Type	Water-cooled, four-stroke
Number of cylinders	1
Swept volume	553 cc
Compression ratio	16.5: 1
Rotation	Clockwise
Bore	80 mm
Stroke	110 mm
Speed	1500 rpm
Continuous power output	3.7 kW at 1500 rpm

3.1 HHO generator kit

3.1.1 HHO Kit Components

HHO generator is basically a fuel cell (electrolytic cell) which decomposes water (H2O) into HHO due to breakdown of water molecules H-HO. HHO has high potential energy and a higher calorific value than that of diesel fuel.

Following are basic components for HHO production for experiment purpose:

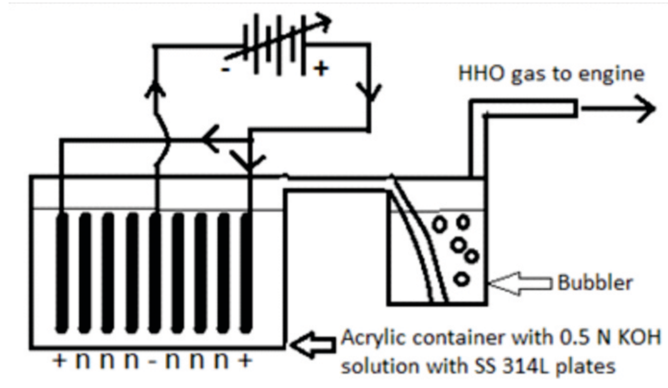


Fig.3: Schematic diagram of HHO gas generator Kit

Closed Tank: - It is used to carry electrolyte and electrodes for the chemical process. The material of tank is to be preferred as plastic and fiber.

Fig. 2: The realized HHO Kit.

Electrodes: - The electrodes of graphite, copper, or stainless steel are used for the chemical of producing the HHO gas.

Electrolyte: - KOH, NaOH, and NaCl are used as the electrolyte.

Hoses: - The hoses are used to supply the produced hydrogen gas to the inlet manifold of the engine.

Battery: - The battery is used to supply the power to the HHO kit.

Connectors: - Clip, clamp, bolts, etc. are used as connectors in the HHO kit.

3.1.2 HHO generator kit for present experimental setup

First, the acrylic containers were fabricated using an 8mm thick acrylic sheet. Ana-Bond, an industrial adhesive, is used to firmly join all the sides of container, whereas, a semitransparent silicone gel was used for sealing the container. Special care had to be taken while using industrial adhesive.

The electrodes made of stainless steel (SS) plates of 316L grade were used. This very rare grade of SS used for making tanks of highly corrosive chemicals. The plates were machined and cut into the size of 4"x6". This size was calculated to be most efficient considering all the points which shall enhance the electrolysis process. The present configuration, i.e. [+ n n n - n n n +] with an average spacing of 0.8 mm (n = neutral), was found to be the best configuration. The Fig.2 explains the construction

The primary bubbler was made with same material as of main container and the secondary bubbler was made using a comparatively weaker plastic so that in case of backfire only the secondary bubbler handles all the damage.

HHO generator used in this study is fabricated for best output and reliability of electrode life operating at a lower temperature compared to commercial set-up. HHO kit used in this experiment consists of a generator and a bubbler.

a.The generator:

As shown in Fig. 3, the generator is an electrolysis cell tuned for maximum output and long lasting electrode life working at lower temperatures compared to industrial setups. The electrolysis takes place in the generator and water, i.e., H_2O is broken down to H_2 + ½ O_2 by supplying electricity through electrodes. 316L steel plates are placed 1 mm apart enabling minimum distance and allowing the bubbles to escape easily. A 0.5 N KOH solution has been used as the electrolyte. The generator consists of an anode, a cathode and an electrolyte which is responsible for the transmission of ions between an anode and a cathode. Anode gets charged which initiates the electrolysis reaction and results in the formation of oxygen and hydrogen.

Basic reaction at the electrodes of an electrolyzer are

Cathode reaction:

$4H_2O\ (l) + \longrightarrow 4e\ 2H_2\ (g) + 4\ OH^-$

Anode reaction:

$4OH^- \longrightarrow O_2\ (g) + 2H_2O\ (l) + 4e^-$

Overall reaction:

$2H_2O\ (l) \longrightarrow 2H_2\ (g) + O2\ (g)$

Bubbler: As shown in Fig. 3, the bubbler is a device which performs two tasks: one it filters the gas produced and second it works as flashback arrestor. The gas produced in the generator has a little amount of steam in it, so when the gas is passed through water the steam in the bubbles gets condensed, and the remaining is HHO gas. If a condition like a flash back arises and the primary flashback arrestor doesn't work, then the flash would come back to the bubbler and stop here and prevent to reach the generator. The spring valve automatically senses the increment in pressure and opens releasing out all the pressure instantly, saving the container and the whole assembly.

Power is supplied to the generator from battery using 8 gauge wires capable of sustaining current over 30 Amp. In between lies an MCB operating at 30 Amp for limiting any abnormal power surge.

The HHO gas produced is fed to the intake pipe just before the inlet manifold, it helps in making a homogeneous air-HHO mixture.

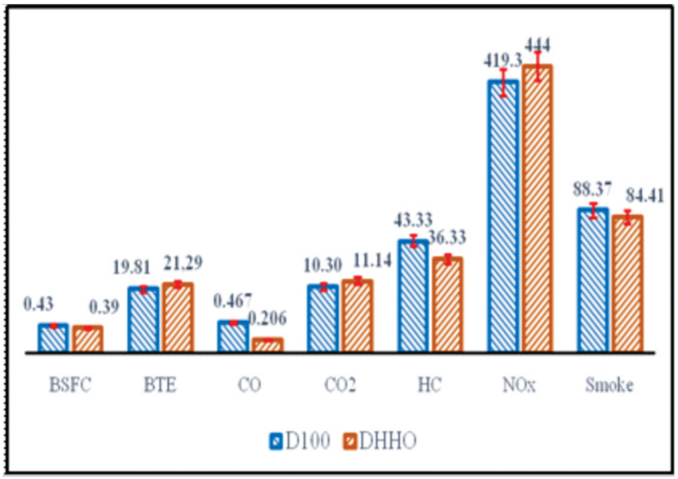
In normal conditions, the HHO generator kit produced about 1500 ml gas per minute. Water replacement technique was used for gas measurement.

$$\text{HHO productivity} = \frac{\text{Volume}}{\text{time}}$$

3.1.3 Challenges faced during fabrication of HHO kit:

a) During fabrication

- Problems faced during machining operations on acrylic plate.
- Steel plates had misaligned holes which took more



- time to refurbish that manufacturing.
- The Container wasn't airtight initially, so silicon sealant was used to cover all of its edges.

Only Paper Gasket was not sufficient for stopping the leakages near the coupling of the containers

- The first experiment was not up to the mark due to the usage of tap water and formation of foam in the container due to reactions of NaOH with the impurities in water.
- Low amps current was drawn because of low conductivity of solution and a high distance between the electrodes.
- Later KOH solution was made and used for electrolysis though there was no foam, but the conductivity was still low at lower concentrations.
- As the concentration was increased above a level, the production rates stated to become constant while the solution became more hotter.

b) Problems faced while testing

- The major problem encountered during the tests was the power supply, a battery was used as a constant source of power supply, but it was difficult to ensure exact supply continuously.
- Maintaining a constant flow of HHO gas was difficult due to the this.

c) Future scope and recommendations

- High Pressure and high-temperature steam reformation system.
- Electronically controlled fuel injection system enhancer with a feedback system.
- A smart Pulse Wave Modulator with feedback from Engine speed and power consumed would improve and control production of HHO gas.

4. RESULTS AND DISCUSSIONS

HHO gas was supplemented with Diesel fuel with the air induced in the engine cylinder. A constant flow rate of 1.5 l/min is assumed from the HHO generator since small variations observed due to variation in the supply from the battery to the kit. Performance and emission characteristics of the engine for diesel (D100) and diesel-Hydroxy gas (DHHO) are presented and analyzed. Engine ran smoothly for DHHO mixture for a wide range of loads without any engine modification. A consolidated chart is shown in fig. 4 to represent various performance and emission parameters at full load condition.

Results show 9% drop in brake specific fuel consumption (BSFC) and 7% increase in brake thermal efficiency (BTE). The emissions of CO, HC, and smoke have been reduced by 56%, 16% and 5% respectively for Hydroxy-diesel mixture as compared to diesel alone. A slight increment in NOx emission of 6% has been noted.

Fig. 4: Data on performance and emission parameters at full load conditions

5. CONCLUSION

The following conclusions are drawn from experimental work:

- The HHO generation kit has been fabricated and installed with single cylinder diesel engine test rig. Experiments have been performed with diesel only and mixture of diesel and Hydroxy gas.
- It has been observed that with 1.5 liters/min mixing of hydroxy gas with diesel improve the performance of the engine. The BSFC has been reduced by 9% and BTE has been improved by 7%.
- The emission of CO, HC, and Smoke reduced with the diesel-hydroxy mixture. The reduction in CO, HC and Smoke was 56%. 16% and 5% respectively.
- The NOx has been increased due to a higher temperature.
- The increment of NOx is 6% with diesel and Hydroxy mixture.
- The diesel-hydroxy mixture would be an alternative to pure diesel to reduce emissions of the diesel engine in future with latest NOx reduction measures/technologies. More experimental work is required to check the effect varying the flow rate of Hydroxy gas in a mixture as well with other operating parameters.
- The performance and emission can be measured with variations of engine operating parameters. The flow rate of Hydroxy can be varied to see the effect on performance and exhaust emissions. Electronic Control Unit (ECU) can be incorporated for better control of diesel and Hydroxy flow rate and injection timing.

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