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Comparative Analysis of Performance Characteristics of CI Engine with and without HHO Gas (Brown Gas)

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Abstract

Internal combustion engine is used in daily life activity. Fossil fuels are primary fuels which are used in IC engines because of increasing consumption day by day its alarming that these will deplete in near future. Researchers in field of inter combustion trying to use alternate fuels to fulfill energy demand of IC engine. Among the others, hydrogen is capturing attention as alternate fuel in engine for proper combustion without smoke as there is no carbon is present in it. In this article, hydroxy (HHO) gas has many excellent combustion properties that can be used for improving performance characteristics of diesel-fired Compression Ignition (CI) engines. Brown gas (HHO) was produced by using the electrolysis process with $KOH_{(aq)}$ as catalyst with stainless steel electrodes in a leak proof plexiglass reactor was presented in ongoing piece of writing. Produced gas is used as supplementary fuel in inlet manifold of engine test bed (modal#TQ200) which has one cylinder, air cooled, four stroke compressed ignition. Performance characteristics of engine were recorded under the same test condition with and without installation of HHO generator. Experimental results were taken over the range of speed from 1950 to 3450 rpm using hydraulic dynamometer at constant load condition of torque 2 N-m. Different engine performance parameters were calculated like engine brake power, the brake specific fuel consumption, the thermal efficiency, the mechanical efficiency and the specific fuel consumption with or without HHO gas. The results clearly indicated that engine's brake power, thermal efficiency and mechanical efficiency increased 22%, 47% 24%, respectively while engine's brake specific fuel consumption and specific fuel consumption (SFC) decreased upto maximum value of 35% and 27% respectively compared with engine operating without HHO generator. Main objectives of this research are to decrease the fuel consumption and increase power and efficiencies of CI engine and successfully achieved as witnessed in results.

Keywords: HHO gas; CI engine; Mechanical efficiency; Thermal efficiency; SFC

Introduction

In modern days, energy demands increased due to increase the population of world. Energy demands fulfilled from fossil fuels such as natural gas and petroleum oils but fossil fuels produced harmful gases after burning and have negative impacts on environment. Many scientist and researcher are working on alternate fuel to control emission and better performance of vehicles [1]. The water hybrid system introduces in vehicles that to produce the hydrogen gas as used as a supplement fuel. It is a cleaner system; one that develops supplemental fuel from unlimited resource water. It has distinctive property that is able to remove pollutants from the air during combustion, even decreases the carbon residue within the engine and improves performance of engines. HHO gas is referred as brown gas which is a weekly bonded water molecule in gaseous state 2:1 molar mixtures of hydrogen and oxygen [2]. HHO production occurs by electrolysis process by using different electrolytes such as KOH, NaOH, NaCl, in different electrode designs in a leak proof reactor [3]. In HHO generator, for production of oxy-hydrogen gas in which different electrode material such as S-302, S-306, S-309 and S-316 L are used with electrolytic solution for electrolysis of water and mixed with conventional fuel like petrol or diesel. It is conducted different performance test of internal combustion engine for calculating efficiency, mileage and exhaust emission [4]. Production of hydrogen at cathode and oxygen at anode occurs due to migration of ions in solutions [5,6].

At anode: $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$

At cathode: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

Overall reaction: $2H_2 + O_2 \rightarrow 2H_2O$ + electric energy + heat

Comparison between properties of diesel and hydrogen are given below in Table 1.

To improve the hydrocarbon combustion in CI engine is done by using hydrogen as supplementary fuel in it. HHO gas exhibits properties that make to more reactive than standard hydrogen. Brown Gas can enhance performance and fuel efficiency [7]. Emission and performance of a Skoda Felicia 1.3 GLXi engine was checked out by the series of laboratory experiments with HHO generator. It was concluded that HHO cell can be incorporated into engine systems without modification. The engine thermal efficiency has been improved up to 10% and reduces fuel consumption up to 34% when HHO gas has been introduced into the air/fuel mixture [8]. Performance of four stroke diesel engine was investigated by effects of using a small amount of H_2/O_2 mixture as an additive. Required amount of H_2/O_2 mixture were generated by electrolysis process. H_2/O_2 mixture has ability to increase over combustion that generating higher peaks pressure closer to TDC, ultimate producing more work. Hydrogen has nine times higher flames speed as compared to diesel. The experimental results showed that 6.1% H_2/O_2 mixture of total diesel which was introduced that caused to increased thermal efficiency by 2.6% at 19 KW, 2.9% at 22 KW, 1.6%

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at 28 KW. The brake specific fuel consumption decreased by 7.3% at 19 KW, 8.1% at 22 KW and 4.8% at 28 KW.H_2/O_2 mixture should not be beyond 5% in enhancing performance of engine. The emission of hydrocarbons, carbon dioxide and carbon monoxide were reduced due to better combustion while NO_x increased due high temperature accessed during combustion [9,10]. Performance and emission of diesel engine were investigated with effect of hydrogen and HHO. Since HHO gas comprises more oxygen which shows higher combustion efficiency and produces better combustion performance than pure hydrogen as an additive fuel [11]. Uniform mixing of hydroxy air and oxygen of HHO with diesel caused to improve combustion which has key role in SFC. Due to high flame range, high A/F ratio, short quenching distance

Properties	Units	Diesel	Hydrogen
Ignition Temperature	K	530	858
Minimum ignition energy	mJ	----	0.02
Flammability Limits	volume % in air	0.7-5	4-75
Stoichiometric A/F ratio	mass basis	14.5	34.3
Limits of flammability	equivalence ratio	----	0.1-7.1
Density at 16 *C* and 1.01 bar	kg/m^3	833-881	0.0838
heating value Net	MJ/kg	42.5	119.93
Flame velocity	cm/s	30	265-325
Quenching gap	cm^2	---	0.064
Diffusivity in air	cm^2/s	---	0.63
Research octane number	---	30	130
Cetane number	---	40-55	---

Table 1: Properties of hydrogen and diesel.

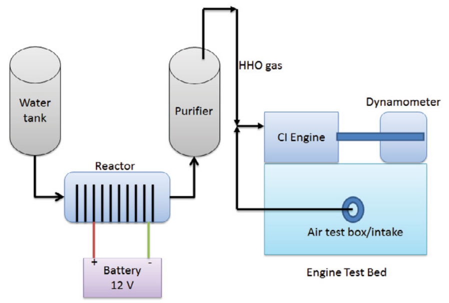

Figure 1: Schematic diagram of experimental setup.

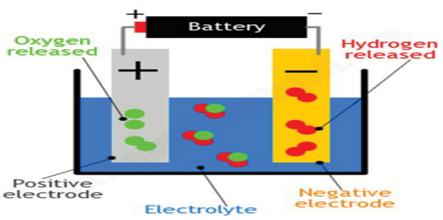

Figure 2: Electrolysis process.

Figure 3: Reactor configuration.

produces complete combustion of diesel at high speed. When engine speed operates below 1750 rpm, control unit decrease automatically current and voltage for electrolysis process that cause hydroxy enriched diesel fuel combustion process and better energy economy [3].

Emission performance of Honda G 200 engines was carried out with effect of HHO gas experimentally. HHO generator was integrated at intake manifold of engine and enhances the combustion efficiency and decrease fuel consumption. Hydrocarbon concentration was affected by presence of HHO gas and speed of engine [12]. HHO generator is easy to integrate with engine without any modification and no hardware component is required to install in the engine. In oxy-hydrogen gas, hydrogen is present. Oxy hydrogen blends with diesel which shows best combustion efficiency and thermal efficiency. Water vapors which are by product of combustion process that decrease combustion chamber temperature and decrease engine detonation. Production cost of procedure gas is high as compared to oxy hydrogen gas because AC power source is required for production of procedure gas using pyrolysis process. 12 V DC supply from battery is required for oxy hydrogen. It is impossible to fit procedure gas generation module with automobile engine. During pyrolysis process, coal is generated as by product [13]. Many researchers have been performed different experimentation on CI engine with HHO gas and biodiesel as supplementary fuel, the following conclusion have been drawn. HHO gas can be integrated with both spark and diesel engines with or without modification. Biodiesel is used as sole fuel or dual fuel in compression engines without modification. HHO and biodiesel utilization may lead to higher thermal efficiency, reduced emission and specific fuel consumption. However, increase in oxides of nitrogen couldn't be stopped without using some treatment methods [14].

Engine was tested with HHO gas at different load application in which brake power increased. Mechanical efficiency increased when engine is operated with HHO gas. Brake thermal efficiency increased when engine operated with HHO gas is more as compared with pure diesel. Emission like carbon monoxide (CO), NO_x, carbon dioxide (CO_2), hydro carbons (HC) are decreased when engine is operated with HHO gas as compared to pure diesel [2].

Experimental Setup

The engine test bed which was aspirated direct injection diesel engine TQ200 with single cylinders having the total capacity of 232 cc, absolute maximum power of 3.5 kW (4.8 hp) at 3600 rev/min, Continuous Rated Power 3.1 kW (4.8 hp) at 3000 rev/min and compression ratio 22:1. The schematic diagram of experimental setup is shown in Figure 1 with symbol of main components.

HHO gas generator

HHO generator is a device in which water could be splitted into its two components hydrogen and oxygen by the process of electrolysis for the production of HHO gas. Chemical decomposition produced by passing an electric current through a liquid or solution containing ions is called electrolysis as shown in Figure 2.

Methodology of HHO generator: Reactor consisted on three components i.e. water tank, purifier and bubbler. In reactor, Jain sheet is placed between the two-stainless steel (316 L) plates which are fitted in leak-proof fiber sheet with help of 316 L stainless steel nuts and bolts. Twenty-nine stainless steel plates are used in this reactor as shown in Figure 3.

Water tank is used as a water storage in which catalyst KOH is added. Oxyhydrogen gas (HHO) is passes through purifier for

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removing water vapours and moisture contents. Bubbler is also used to purify the HHO gas from the moisture. Assembly of components are shown in Figure 4.

Electrolysis voltage, current and short circuit are checked via a digital Multimeter (Figure 5).

Letters "D", "L", "T", "W" and "H" represent "diameter", "length", "thickness", "width" and "height", respectively in given Table 2.

HHO generator provides 5 l/min gas with voltage and current is

Figure 4: Components of HHO generator.

Figure 5: Digital multimeter.

Items	Quantity
316 L stainless steel electrode plates (115 mm × 70 mm × 2 mm, D × L × T)	29
Plexiglas plates (350 mm × 130 mm × 20 mm, L × H × T)	2
Water level system	1
Water tank (200 mm × 200 mm × 150 mm,W × L × H)	1
DC device (DC supply)	1
Multimeter	1
Catalyst (KOH)	~1% by mass

Table 2: Basic system materials and quantity.

Specifications	Details
Maximum gas supply	5 L/min
Electrodes (anode-cathode)	316L stainless steel plates
Maximum electrolysis voltage and current (≥ 1900 rpm for CI)	12 V-14.1 A
Electrolyte (1% by mass)	KOH aqueous solution
Water container volume	5 L

Table 3: Technical specifications of the HHO generator.

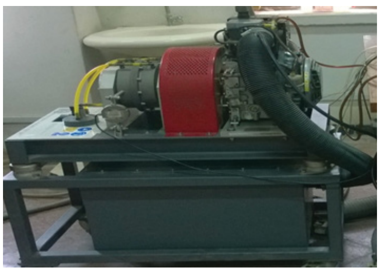

Figure 6: CI engine modal.

Items	Specifications
Fuel type	Diesel
Absolute maximum power	3.5 kW (4.8 hp) at 3600 rev. min^{-1}
Continuous rated power	3.1 kW (4.8 hp) at 3000 rev. min^{-1}
Bore	69 mm
Stroke/crank radius	62 mm/31 mm
Connecting rod length	104 mm
Engine capacity	232 cm^3 (0.232 L) or 232 cc
Compression ratio	22:1
Oil capacity	2.6 Litre

Table 4: Technical specifications of CI test engine.

Figure 7 : CI engine with HHO generator.

12 V, 14.1 A respectively. Capacity of HHO generator is described in Table 3.

CI engine

HHO gas injection to CI engine: Hydroxy gas (HHO) is injected directly in engine without modification. Before entering intake manifold, HHO gas is transferred to 1/3 water-filled pot to prevent backfiring. Non-return valve is used to prevent rising of gas pressure over 1 bar in the container. Hydrogen and oxygen generated by the electrolysis process of water by a unique electrode design which is in their mono-atomic state. It is an unstable state of H_2O vapor, more energy is achieved compared to hydrogen burning with oxygen.

Pulverized water clashes the fuel and they unite with each other. Due to densities difference, water acts as a core and the fuel leads to be water shell. During compression stroke, pressure and heat increases, the water explodes to steam and consequently, the fuel gets atomized.

After ignition, temperature increases rapidly in cylinder which results water to be splitted into hydrogen and oxygen and re-ignition occurs by which increased combustion efficiency. Due to the simultaneous production and consumption of hydrogen, no storage is necessary, which results in safe operation. HHO is generated and used as a sole fuel in CI engines to benefit from peculiar features and minimize disadvantages of hydrogen (Figure 6) (Table 4).

Synchronization with control panel: Versatile Data Acquisition System (VDAS) connected with pressure transducer, temperature sensor and fuel consumption gauge. The ambient pressure and engine cylinder pressures at inlet and outlet can be calculated with help of pressure transducers attached with engine test bed. Cylinder temperature can be calculated before and after combustion process with the help of temperature transducer. It indicates speed, power and torque of engines on digital display (Figure 7).

Results and Discussion

HHO gas was used as a supplementary fuel in engine with single cylinder, four strokes but without any modification in this experimentation. Various parameters such as Specific Fuel Consumption (SFC), break power, mechanical efficiency, thermal efficiency, break specific fuel as function of engine speed was recorded and promising results were reported by conducting tests.

Specific fuel consumption and engine speed

The decline in SFC is due to uniform mixing of HHO with air (high diffusivity of HHO) as well as oxygen index of HHO gas which assists diesel during combustion process and yields better combustion. An average decrease of 27% is achieved in SFC by using HHO gas. The improvement in engine brake thermal efficiency for the HHO enriched engine is more evidently seen at low manifold absolute pressure conditions.

This can be attributed to that, at high speed, the diesel is hard to be completely burnt at lean conditions due to the increased residual gas fraction (RGF) and poor mixing. Since HHO gains a high flame speed and wide flammability, the addition of hydrogen would help the diesel to be burned faster and more completely at high speed conditions.

Low ignition energy of HHO-air mixture derives diesel even to be burned safely under leaner conditions. However, at low speeds (≤2500 rpm), low lean flammability limit prevents HHO to have positive influence on combustion efficiency due to mixture requirement around

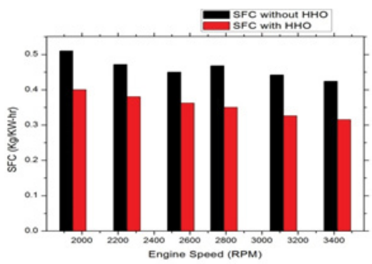

Figure 8: SFC and engine speed.

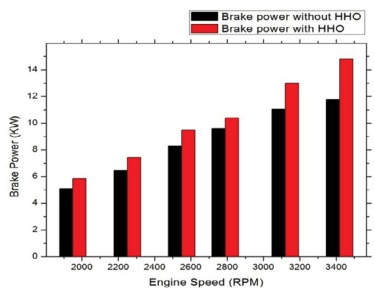

Figure 9: Brake power and engine speed.

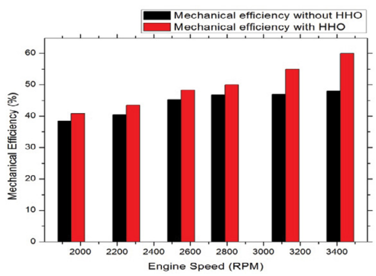

Figure 10: Mechanical efficiency and engine speed.

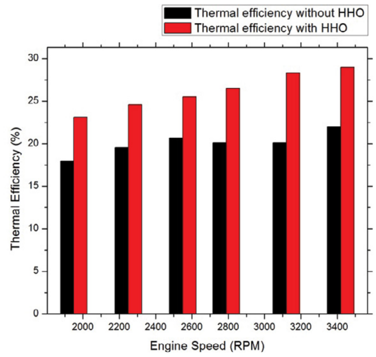

Figure 11: Thermal efficiency and engine speed.

stoichiometric conditions and high volume occupation of HHO causes reduced volumetric efficiency unless load is induced to the system. The decreasing curve of the specific fuel consumption is more smooth and fine along with HHO gas instead of simple combustion as shown in Figure 8.

Comparison between SFC with and without coupling HHO generator and results presented column chart in clearly indicates that betterment in introducing HHO during the suction stroke. Maximum value is obtained at low rpm compared to high speed with constant flow rate of hydroxy gas, average 27% of fuel consumption was decreased is recorded.

Brake power and engine speed

Brake power of CI engine increased 16% by using HHO at constant load. After 2500 rpm, the gain of brake power exceeds up to 22%. At high rpm, the engine is working smoothly compared to speed when HHO gas is introduced into it as shown in Figure 9.

Overall increasing trend of brake power w.r.t engine is followed by engine while integrating the generator. Maximum brake power is obtained at 3400 rpm as shown in above mentioned figure.

Mechanical efficiency and engine speed

Mechanical efficiency of engine is achieved by 7% at 2550 RPM, it is increased about 14% at 2850 RPM and it gradually increases to 24% at 3400 RPM. This indicates that the engine is working more smoothly at high RPM when HHO gas is introduced into it (Figure 10).

Thermal efficiency and engine speed

Thermal efficiency of engine is achieved by 27% at 2550 RPM, while incremental trend is obtained same as other parameters and is about 30% at 2850 rpm compared to thermal efficiency without HHO; furthermore, by accelerating the engine up to 3200 rpm 47% increase was witnessed. This indicates that the engine is working more efficiently at constant load when HHO gas is introduced into it (Figure 11).

Brake specific fuel consumption and engine speed

Similar to above mention parameters, for the calculation of brake specific fuel consumption engine was operated at various accelerating speed ranges from 1950 rpm to 3450 rpm and results undoubtedly showing that it was also reduced up to 35% by using HHO gas (Figure 12). Decline of the specific fuel consumption curve is uniform with using HHO gas instead of simple combustion.

Conclusion

The present study has investigated efficiency and performance of

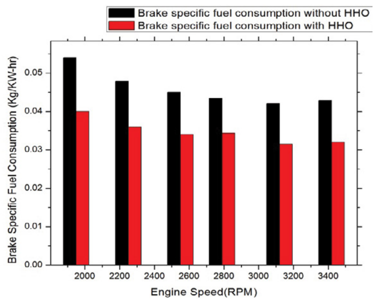

Figure 12: BSFC and engine speed.

CI engine in dual fuel mode with HHO gas in induction air without any modification in design of engine. All data points are carried at least 5 times for each result. It is concluded that

• HHO generator can be incorporated with existing Engine without any modification.

• Best available catalyst was $KOH_{(aq)}$, with production of gas 5 L/min.

• It is obtained 55% hydrogen and 45% oxygen by electrolysis of water in HHO generator but theoretically it is 66.6% hydrogen and 33.3% oxygen.

• Specific fuel consumption has been decreased average of 27% by using HHO gas.

• Brake power of CI engine has been increased up to 22% by using HHO using dynamometer at constant load.

• Mechanical efficiency has been increased up to 24% at high speed using dynamometer at constant load.

• Thermal efficiency has been increased up to 47% at high speed using dynamometer at constant load.

• Brake specific fuel consumption which is reduced up to 35% by using HHO gas.

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