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Experimental Investigation using an On-Board Dry Cell Electrolyzer in a CI Engine working on Dual Fuel Mode

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Abstract

In this work, an integrated system of electrolyzer with CI engine which introduces HHO gas into the air intake is experimented. The system was installed to the engine with all the accessories including the required safety measures. The experiments were conducted on a 553 cc single cylinder constant speed Kirloskar engine. Dry cell HHO generator has been installed to the test engine. The test gave the result such that the fuel consumption has been reduced by 6 - 12% with an HHO gas supply of 1 LPM along with the engine air intake.

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Keywords: HHO gas, Duel fuel mode, CI engine.

1. Introduction

The main input for the economic development of any country is presently based on the commercial energy availability and its usage. The main source of energy we depend on are non-renewable sources [1]. The conventional source that we depend now are very less to meet the future energy demand. Also, the increase in the automotive vehicles and the emissions produced by these led to the search for alternative fuels. Few such alternate fuels were bio-diesel, bio-ethanol, biogas, hydrogen, and solar energy. Hydrogen is one of the most abundant energy source

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and the best alternative fuel due to its high heating value, availability and high burning velocities [2]. It can be used as an alternative fuel in automobiles. One the major drawback of hydrogen is its storage and hence here comes into picture, the concept of on-board hydrogen production by water electrolysis. Electrolysis of water separates hydrogen and oxygen which are together known as oxyhydrogen (HHO) gas and which can be fed into the engine. The fuel consumption and exhaust gas emissions from the engine are to be studied extensively before the use of on-board dry cell electrolyzers in the CI engines [3].

Nomenclature

A/F	Air fuel ratio
BP	Brake power
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
CI	Compression ignition
DOE	Design of experiments
FC	Fuel consumption
HHO	Oxyhydrogen gas
IC	Internal combustion
ITE	Indicated thermal efficiency
LPM	Litres per minute
TFC	Total fuel consumption

2. HHO gas generator

Electrolysis of water is the decomposition of water to hydrogen and oxygen with the passage of electric current through the water. Pure water is considered for electrolysis of water and to increase the electrical conductivity of pure water electrolytes such as sulphuric acid (H_2SO_4), potassium hydroxide (KOH), sodium hydroxide (NaOH), etc. are added [4].

Electrolysis of water can be done using electrolytic cell which consists of electrodes and electrolyte. The electric power source is connected to two electrodes (anode and cathode) which are made of inert metals such as platinum, stainless steel, iridium, etc. During electrolysis, the hydrogen will be generated at the cathode and oxygen will be generated at the anode and the amount of hydrogen generated will be twice that of oxygen. The reaction taking place at the electrodes and overall reaction is as follows:

$$\text{Cathode (reduction): } 2\,H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2\,OH^-_{(aq)} \tag{1}$$

$$\text{Anode (oxidation): } 4\,OH^-_{(aq)} \rightarrow O_{2(g)} + 2\,H_2O_{(l)} + 4\,e^- \tag{2}$$

$$\text{Overall reaction: } 2\,H_2O_{(l)} \rightarrow 2\,H_{2(g)} + O_{2(g)} \tag{3}$$

The two types of electrolytic cell are wet cell electrolyser and dry cell electrolyser. In a wet cell the electrodes are dipped in electrolytes such that the entire electrode material is surrounded by electrolyte where as in a dry cell the electrolyte is trapped inside the rubber gasket which separates the electrode plates. As compared to wet HHO cell, dry HHO cell has many advantages. In dry cell electrolyzer, the electrolyte is stored in an electrolytic tank which also acts as a bubbler and electrolyte enters the cell under gravity. The outlet of the electrolyser is connected to the intake manifold with safety devices. It requires less current as compared to wet cell for production of same amount HHO. The maintenance cost of the dry cell is also low. From the above description it is clear that the dry HHO cell will be more suitable for HHO gas generation [5, 6]

3. Optimization of Dry Cell Electrolyser

The possibility of hydrogen production by the electrolysis of water was established way back in 18th century itself. The minimum voltage needed to initialize water electrolysis consists of three basic components including the theoretical reversible voltage. In order to increase the efficiency of water electrolysis, the voltage requirement must be maintained low. If the electrolyzer functions under lower voltage for same current drawn, then the volume of gas generated increases.

3.1. Experimental Arrangement

The electrolysis of water was conducted at atmospheric pressure using stainless steel (316L), which has low carbon content. To find out the lowest voltage consumption between the electrodes, design parameters such as, space between electrodes, type of electrolyte, concentration of electrolyte and surface finish of electrodes were changed/varied.

3.2. Optimization Methodology

Design of Experiments (DOE) technique was used to study the influence of various design variables on the response of the controlled experiments. The steps involved in DOE are to identify the independent variables that affect the product or process and to study their effect on response or other variables. The factors that were retained constant for the present study (identified from earlier works) are

1. Electrode material (Stainless steel - 316L)
2. Spacer material (Neoprene gasket)
3. Current density (0.1 A/cm^2)
4. Pressure

In this work, following four more factors were considered (each at two levels)

1. Space between the electrodes (2mm and 3mm)
2. Type of electrolyte (NaOH and KOH)
3. Electrolyte concentration (20 % and 30 %)
4. Electrode surface (smooth and rough)

The response value of all the experiments were taken showing the minimum voltage required to activate electrolysis adequately between the two adjacent plates. Two level factorial design method was used for optimization. The factors are such that, two of them are numeric and the other two are categorical. The inputs are given to Design Experts-7 software and it generates a run table with 16 runs that are required.

The experiments on dry cell were conducted according to the run order and the response voltages were recorded. The main aim behind the optimization is to find the combination of parameters showing minimum value of the voltage. This software also takes into account the interaction between different factors. Thus, the optimization of dry cell electrolyzer was performed using DOE and a model equation was generated, which could be used for predicting the response voltage at different input conditions.

3.3. Result of DOE

The optimized result of the dry cell electrolyzer, indicates that KOH is the best electrolyte and the space between the electrodes is 3 mm. The optimum concentration of the electrolyte is 30 % and the best electrode surface is rough. The minimum voltage per gap obtained is 1.829 V corresponding to these optimum values of the other parameters. The dry cell electrolyzer fabricated is shown in Fig. 1(a).

4. Test on IC Engine

The HHO gas generated from the dry cell electrolyzer was supplied to the engine through a water trap, silica-gel absorber, flow meter (rotameter) and a flame arrestor (Fig. 1(b)). The water trap and flame arrestor acts as safety devices which eliminates the chance of back fire from the engine. HHO gas generated from the electrolyzer was passed through the Silica-gel absorber, in order to remove the traces of water vapour which may affect the performance of the engine. The flow meter (not shown) was used to measure the amount of HHO gas supplied to the engine and the DC power source was used to supply the energy required for the electrolysis of water for HHO gas production.

The HHO gas produced by electrolysis was supplied to the CI engine and the diesel fuel consumption and exhaust gas emissions were recorded. The amount of HHO gas that was supplied to the inlet manifold can be controlled by a rota-meter. The engine used for test was a constant speed (1500 rpm) Kirloskar engine with rated power 5 HP and cylinder volume 553 cc. Experiments were conducted with four different flow rates of HHO gas (such as, 0.89 LPM, 1.37 LPM, 1.66 LPM and 2 LPM). All the observations obtained were compared with the conditions corresponding to the use of 100 % diesel fuel.

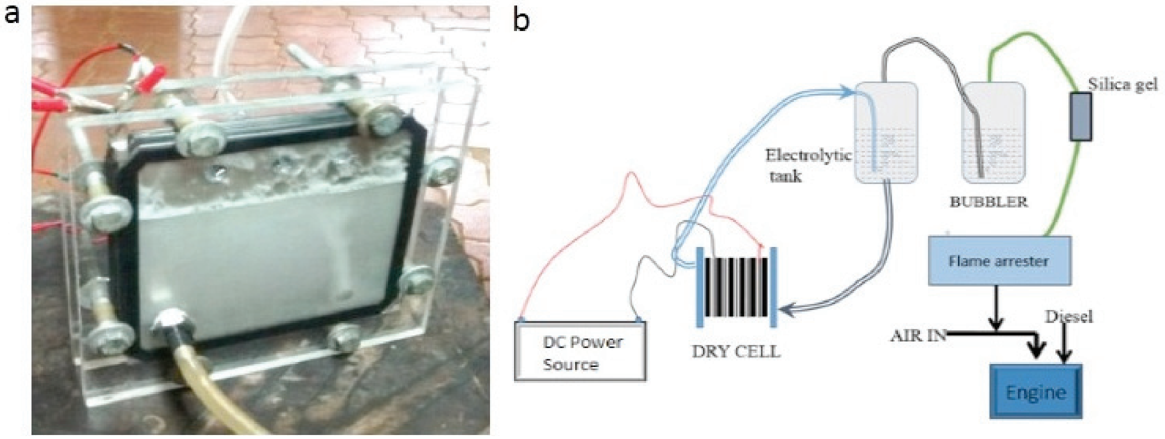

Fig. 1. (a) HHO dry cell electrolyzer, (b) Schematic diagram of the HHO gas supply system.

5. Results and Conclusions

5.1. Effect of Brake Thermal Efficiency (BTE)

Brake thermal efficiency is a significant terminology that indicates the efficiency of an engine and is the percentage of input energy available as the output or it is the ratio of output power available at the crank shaft to the input energy supplied in the form of chemical energy.

When HHO gas was introduced to the engine, BTE was found to increase with increasing flow rates of HHO gas (Fig. 2(a)). The maximum BTE obtained was 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.

5.2. Effect on Diesel Fuel Consumption (FC)

In constant speed engines, the diesel fuel consumption increases with increase in load to maintain the speed constant (Fig. 2(b)). The maximum saving in the 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 reduction in fuel consumption was due to better combustion; the uniform mixture of air especially the oxygen of the original A/F ratio and HHO gas which assists diesel during combustion process. The properties of hydrogen such as, short quenching distance, high flame speed and wide flammability range enables diesel fuel for complete combustion.

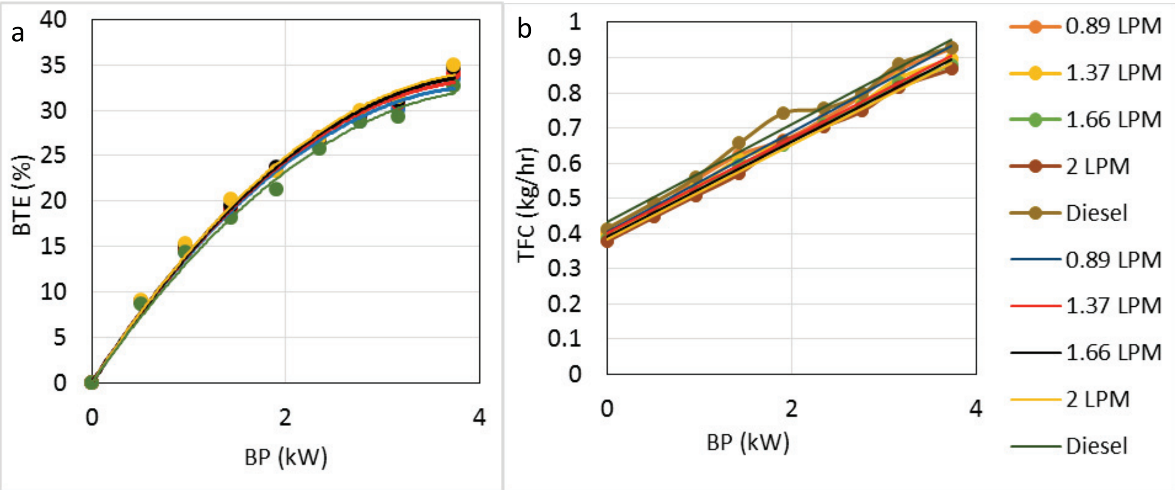

Fig. 2. (a) Variation in BTE with HHO gas addition, (b) Variation in FC with HHO gas addition.

5.3. Effect on Brake Specific Fuel Consumption (BSFC)

Brake specific fuel consumption is a measure of fuel efficiency and is defined as the amount of fuel required to produce unit power output of 1 kWh. 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 (Fig. 3(a)). The reduction in fuel consumption was due to better combustion. Since the diesel fuel consumption decreases with addition of HHO gas, the BSFC also decreases accordingly.

5.4. Effect on Air-Fuel Ratio

The air-fuel ratio is the ratio of mass flow rate of air to the mass flow rate of fuel. With addition of HHO gas, some amount of air gets replaced and the diesel fuel consumption also gets reduced. The addition of HHO gas in intake manifold is expected to reduce the air intake and the oxygen present in the HHO gas will be sufficient for the combustion of hydrogen. So there will be excess amount of air due to reduction in fuel consumption, which results in increased in air-fuel ratio (Fig. 3(b)).

5.5. Effect on Indicated Thermal Efficiency (ITE)

Indicated power is the power generated inside the engine cylinder to overcome the load and the frictional power. It is the sum of brake power and frictional power and is the percentage of input energy available in the engine cylinder. ITE is due to better mixing of hydrogen with air which results in better combustion and also in hydrogen enriched engines, it could be found that the ITE increases with increase in HHO gas addition (Fig. 4(a)). The maximum ITE was 56.25 % at a load of 14.7 kg with diesel and it was increased by 4.03 % with the addition of 2 LPM HHO gas. Higher has an excellent lean burning ability which increases its thermal efficiency.

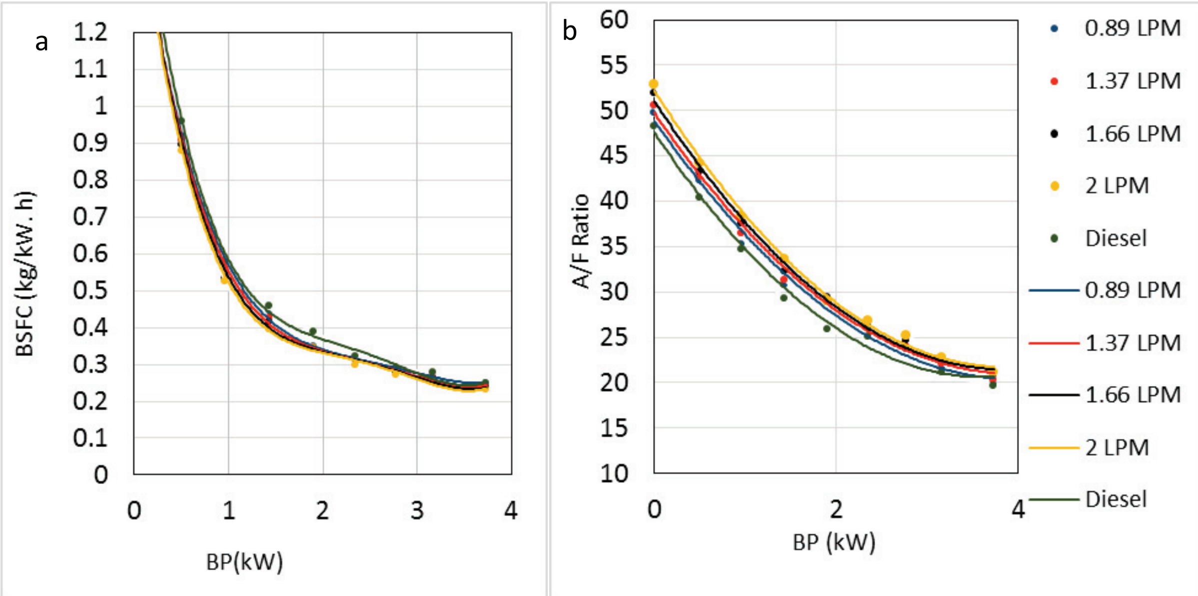

Fig. 3. (a) Variation in BSFC with HHO gas addition, (b) Variation in A/F ratio with HHO gas addition.

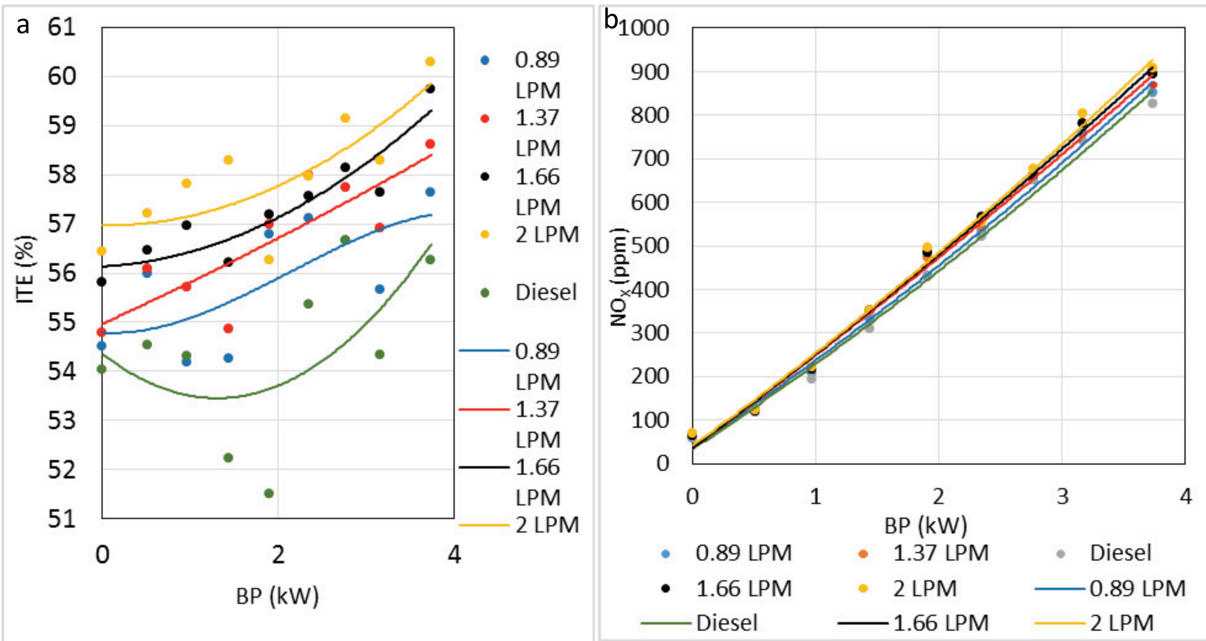

Fig. 4. (a) Variation in ITE with HHO gas addition, (b) Variation in NO_x % in emission with HHO gas.

5.6. Emission Characteristics

The various emissions at the exhaust were measured using a flue gas analyser which gave the percentage of CO_2, CO, HC, O_2 and NO_X (Fig. 4(b), Fig. 5(a) and Fig. 5(b)). From the results it is observed that the percent of O_2 content seems to increase with the addition of HHO gas. The increase in combustion efficiency and decrease in fuel consumption, results in increased percentage of excess air at the exhaust. CO_2 is the major product of combustion of diesel. The carbon dioxide emission tends to decrease with the addition of HHO gas, due to the increase in combustion efficiency, thereby decreasing the diesel consumption. HHO gas does not contain any traces of carbon. The decrease in diesel consumption with the addition of HHO gas and also the increase in burning efficiency, the partial combustion of carbon fuel get reduced, resulting in lowered CO emission.

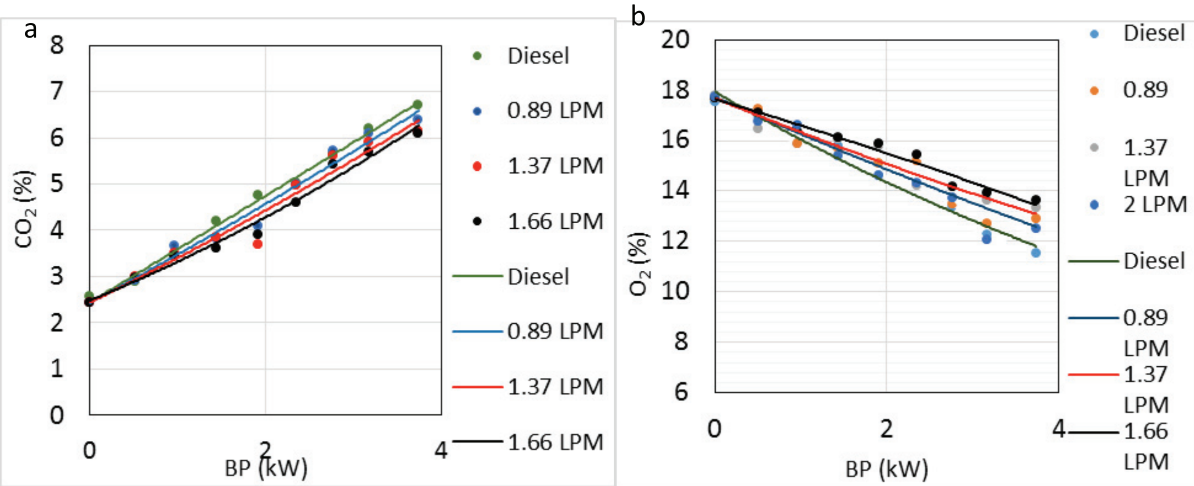

Fig. 5. (a) Variation in CO_2 % in emission with HHO gas, (b) Variation in O_2 % in emission with HHO gas.

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 substituted as a secondary fuel without changing the present design of engine.

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