Experimental Investigation of Performance and Emission Characteristics of Hybrid Fuel Engine

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Abstract

Together with the growing economy in different parts of the world, there is an increasing demand for energy, thus relying on fossil fuels. As there are problems arising due to global warming and environmental degradation related with usage of fossil fuels, demand for alternative fuels is always high. Hydrogen being a green additive fuel is a potential renewable fuel for internal combustion engines, gas turbines, fuel cells etc. It has the advantage of ultra-low pollutions and high efficiency for these applications. The project consist of an on board hydrogen unit along with 4-stroke air cooled engine. The hydrogen produced in the unit was naturally aspirated to a petrol engine through intake of carburetor to substitute the total fuel energy at four engine loads at the engine speed of 750 rpm. The engine performance characteristics and emissions were experimentally investigated and various graphs were plotted to study the effects of these factors at four engine loads. The results obtained showed that the engine with addition of hydrogen had an efficiency of 21.3%. The combined effect of water injection decreased the former efficiency by 4.3%. The net efficiency of the entire setup including hydrogen and water injection was 17%.
Keywords: Hydrogen, Performance, Emission, Efficiency

I. INTRODUCTION

In the present scenario, renewable energy is a field where a lot of studies and researches are being conducted. The main objectives are to find a commercially viable alternative fuel which has reduced emissions. The emissions norms are becoming more stringent as the pollution levels are way above the acceptable limits. The proposed alternatives are ethane, methane, bio-diesel and hydrogen. Of this hydrogen has been proved as to be a promising alternative to fossil fuel used in IC engines, mainly petrol engines. Hydrogen usage in diesel engines is not very common as the proper mixing is not available The properties of hydrogen in comparison to petrol, shown in Table 1, makes it a green additive fuel for IC engines.

Table -1:
Comparing Properties of Hydrogen and Petrol

Properties	*Hydrogen*	*Petrol*
Molecular Mass (g/mol)	*2.016*	*107*
Density (g/cm^3)	*$83.764*10^{-6}$*	*0.70-0.75*
Stoichiometric fuel to air ratio(F/A)	*34.3*	*14.6*
Minimum ignition energy (mJ)	*0.02*	*0.24*
Ignition temperature (K)	*858*	*530*
Lower heating value (MJ/kg)	*120*	*44*
Quenching gap (cm)	*0.06*	*0.2*

Previous works involving hydrogen addition used a dual fuel system in which the petrol was not completely replaced but the consumption rate was reduced by the use of hydrogen. The dual fuel reduced fuel consumption by about 30%. The engine was run on hydrogen and petrol during part loads and at full loads only petrol was used to obtain the required power. In the later stages operating conditions were modified to reduce the emissions. The noticeable techniques used were operating on lean mixture and increasing the hydrogen supply rate. In 1800's the first hydrogen powered IC engine was invented by Francois Issac de Rivaz. But at that time the invention did not get enough attention as petrol and diesel fuels were available abundantly. But the depleting fuel resources caused the introduction of hydrogen for transportation in the market since 2000. The car manufacturing giants such as BMW, Mitsubishi, Toyota and Honda have introduced mid-range market segments for hydrogen powered petrol engine.

As hydrogen can be used as a viable additive for green fuel, the next issue was to find a satisfactory method for the effective and safe administration of hydrogen into the engine. The handling of hydrogen poses a safety issue as it is highly inflammable. The introduction of hydrogen into the petrol engine can be done either by using a separate hydrogen cylinder or by setting an on-board water electrolysis unit. The use of hydrogen cylinder would ensure a continuous flow rate of hydrogen. But the replacement and the added weight of the hydrogen cylinders are the main troubles. Method of hydrogen on-board hydrolysis unit handles the safety issue of hydrogen storage by the production of hydrogen only when required. In either method, hydrogen is mixed with the fuel by the simplest method of external mixing process, where the hydrogen is mixed with air in the inlet manifold of the carburetor and the mixture is drawn into the inlet port. The mixing of hydroxygen or hydrogen in the carburetor poses a problem of back-firing due to the lower ignition energy of hydrogen.

On considering the impact on the environment, hydrogen as alternative fuel eliminates the emission of Sulphur Oxides (SOx), Oxides of Carbon (CO and CO2), Unburned HydroCarbons (UHC) and soot. But there would be an increase in Oxides of Nitrogen (NOx) due to the higher in-cylinder temperatures by hydrogen. Supplying hydrogen leads to higher local temperature resulting in higher NOx formation rate. The main techniques to control NOx emissions are water injection, addition of diluents, turbo-charging with intercooling, etc. Also hydrogen causes another problem of hydrogen knocking which induces large magnitude of mechanical stress on the cylinder walls. Water injection technique used here is a solution for hydrogen knocking also. But pure water cannot be injected into the engine as it may lead to corrosion and mixing with the lubricating oil.

In this study, the use of hydroxygen as a fuel additive was used along with water injection in a petrol engine. An on-board water electrolysis unit is incorporated to avoid the problem of hydrogen storage. A water injector was fitted near the inlet manifold to control the temperature rise due to hydrogen combustion and control NOx emissions. The load test was performed at a constant speed of 750rpm using a brake dynamometer. Similarly by keeping the speed constant the emissions were analyzed to check the effect of water injection. The graphs for the performance and emissions characteristics were plotted.

II. EXPERIMENTAL ANALYSIS

A. Experimental Set Up:

In this research a single cylinder, four stroke, air cooled spark ignition engine is used which is connected to a brake drum for mechanical loading (figure 1). The detailed specifications of the engine used are given in table 2. A slight modification is made to the test engine by introducing a multi-point 4 nozzle water injector into the inlet manifold which is electromagnetic type. The energy released while burning hydrogen is more than that of petrol which results in increased cylinder temperature leading to increased NO_x emission.

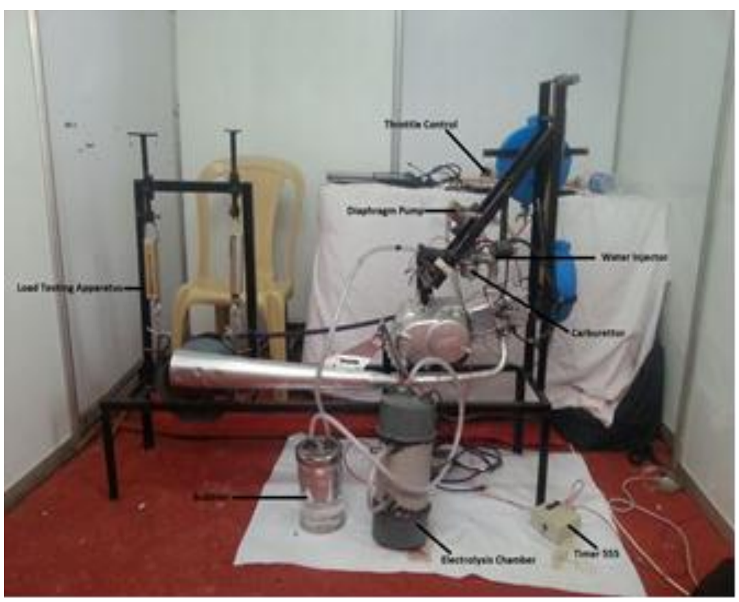

Fig. 1: Experimental Setup

To limit this problem water injection is been provided which injects coolant at regular intervals (20seconds) using a controller. The injection fluid used in this experiment is lathe coolant rather than pure water. Other components include hydrogen unit, bubbler, diaphragm pump (12V, 20W) and a 555 timer (12V, 100W).

Hydrogen unit consist of a tank with SS plates as electrode and a solution of NaOH in water. There is always a chance for back fire from engine if the unit is directly connected then this backfire could result in an explosion, to avoid such a problem bubbler is given and it also helps in identification of hydrogen formation through bubbles. Diaphragm pump is provided to pump the lathe coolant from coolant tank to the injector for water injection. Since the water injector used is an electronic device there is need for a controller to control the water injection timing and 555 timer serves this purpose.

Table -2:
Engine Specifications

Make and model	*Hero Honda CD100 petrol engine*
General details	*Four stroke Air Cooled spark ignition engine*
No of cylinders	*Single cylinder*
Bore	*50mm*
Stroke	*49.5mm*
Maximum power	*7.5bhp @ 8000rpm*
Maximum torque	*0.73 @ 5000rpm*
Swept volume	*99cc*

Load test were conducted for performance evaluation using a tachometer and burette. The CO, THC, NOx emission was measured by Horiba MEXA-7100DEGR. The test was conducted under constant speed of 750 rpm at different loads.

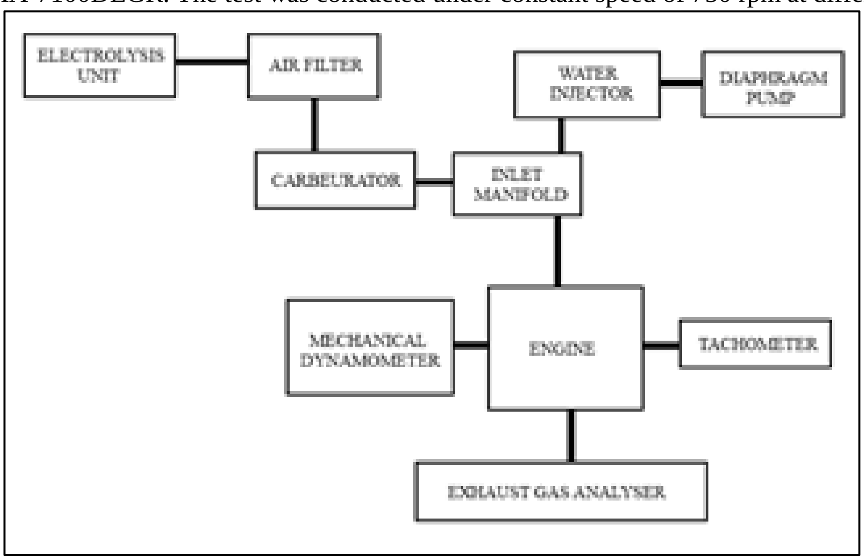

Fig. 2: Block Diagram of Experimental Setup

B. Experimental Method:

The tests were conducted under a constant speed of 750 rpm at different loads. The engine was started for warm up using petrol for certain time. Load test and emission test were done for three test conditions.

1) Test condition 1 - When engine run with petrol.
2) Test condition 2 - When engine run with petrol and hydroxygen mixture.
3) Test condition 3 - When engine run with petrol and hydroxygen mixture along with water injector.

For conducting load test, maximum load was first determined. The engine was started with no load condition. By keeping a constant speed of 750 rpm which is half speed at the top gear, the engine was loaded up to maximum load and time for 5ml fuel consumption (using a burette and stop watch) was noted in each load.

Hydroxygen was introduced through the carburetor where it adjusts the air fuel ratio, there by replacing some of the petrol by hydroxygen thereby reducing petrol consumption. Since there are chances of backfire from engine, bubbler is provided between the electrolysis unit and the hydrogen inlet at the carburetor, to avoid such a problem. For test 3 a water injector and 555 timer was used to provide water injection at an interval of 20 seconds. Hydroxygen flow rate was determined by measuring the time takes for 5ml drop of water in the electrolysis chamber by providing a level indicator.

III. RESULT AND DISCUSSIONS

A. *Performance Characteristics:*

1) Brake Thermal Efficiency:

The brake thermal efficiency for three cases, i.e. pure gasoline, gasoline & hydroxygen addition, and, gasoline & hydroxygen along with water injection are plotted against the load for comparison and is given in the figure 3. It was observed that brake thermal efficiency increases with load.

From the graph it was observed that brake thermal efficiency values increases with load for hydroxygen addition but was decreased with water injection still it was higher than pure gasoline. The maximum brake thermal efficiency was observed at maximum load at 750 rpm.

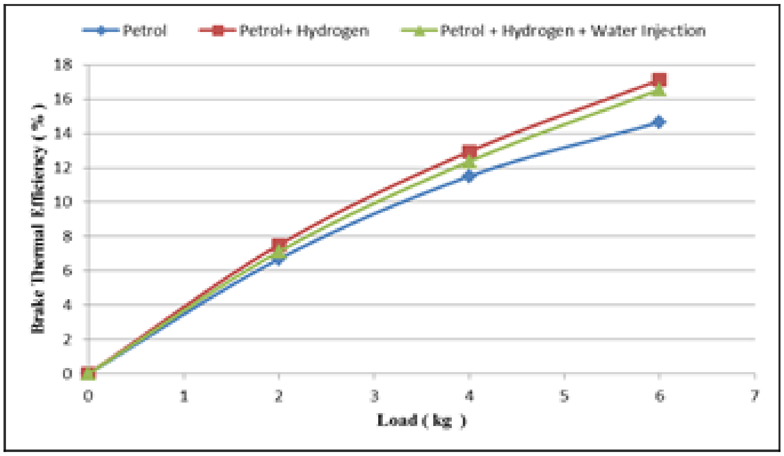

Fig. 3: Variation of Brake Thermal Efficiency with Load

The flame temperature of hydrogen is about 5 times the flame temperature of gasoline and higher burning speed improves thermal efficiency. Also, hydrogen has a wider flammability limits than gasoline. Due to these reasons, hydrogen enriched gasoline mixture fuel will achieve shorter burning continuance and more complete combustion can be observed compared to pure gasoline.

Thus, combustion at constant volume can happen which means the SI engine resembles to a ideal cycle due faster burning speed of hydrogen-gasoline blends. On the other hand there is rise in cylinder temperature and pressure with hydrogen addition. However, these instantaneous pressure rise and drops which are observed in hydrogen enriched gasoline engines limits post combustion period resulting in reduced exhaust losses. Also, cooling loss of engine is reduced due to shortened combustion period. However; the cylinder temperature reduces with water injection as water vapour absorbs heat because heat capacity of water is high. For this reason, there is a slight decrease in thermal efficiency with water addition.

2) Brake Specific Fuel Consumption:

The Brake Specific Fuel Consumption for three different test conditions is plotted against the load and is given in the figure 4.

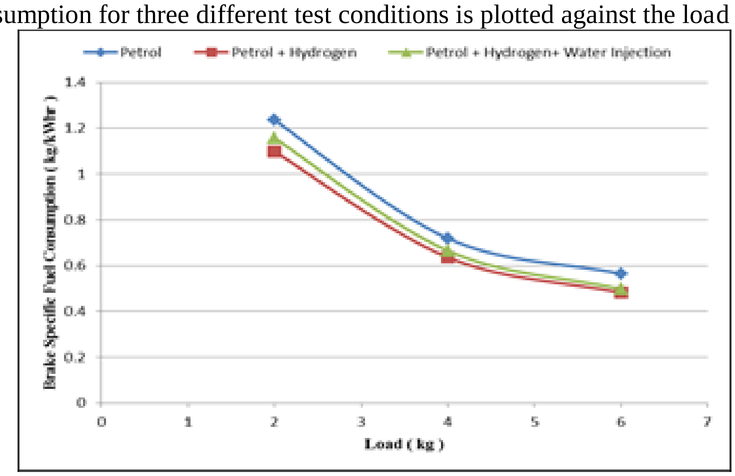

Fig. 4: Brake Specific Fuel consumption

From the graph its was observed Brake Specific Fuel Consumption values decreases along with load for hydroxygen addition but was increased with water injection still it was lower than pure gasoline. The reason for rapid increase in brake specific fuel consumption with reduction in throttle opening is that frictional power remains essentially constant while the indicated power is being reduced, the brake power drops more rapidly than fuel consumption and thereby the brake specific fuel consumption rises .

3) Total Fuel Consumption:

The total fuel Consumption for three different test conditions are plotted against the load and is give in the figure 5.Total fuel consumption is simply defined as the amount of amount of fuel consumed in one hour. It is obvious that the Total fuel consumption will increases with load.

From the graph its was observed total fuel Consumption values increases along with load for hydroxygen addition but was decreased with water injection. Still it was higher than pure gasoline. The total fuel consumption was found to decrease in the case of adding hydrogen as it is substituted in the total fuel energy and thus reducing the amount of petrol needed for combustion. With the water injection added to the above case causes the total fuel consumption to increase slightly because the net fuel energy needed for combustion was increased due to presence of water in the air fuel mixture.

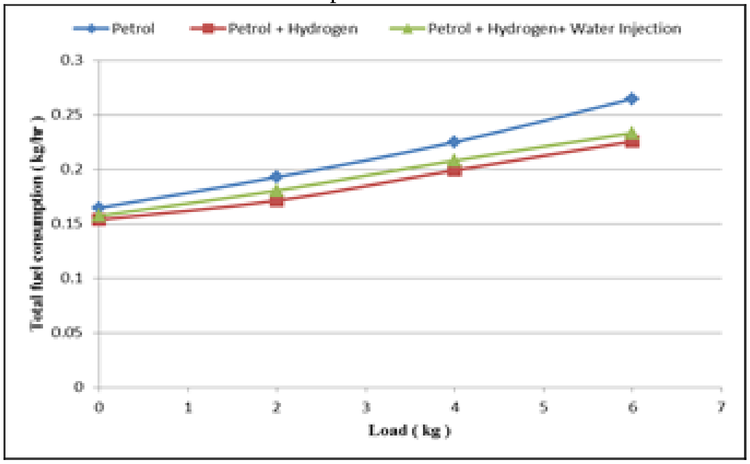

Fig. 5: Variation of Total Fuel Consumption with Load

B. Emission Characteristics:

1) CO Emission:

Carbon monoxide is a colourless, odourless, toxic gas which is formed by incomplete combustion of carbon materials which otherwise would be converted into carbon dioxide on full oxidation. If the amount of oxygen is increased, carbon dioxide will be formed. Figure 6 shows the variation in carbon monoxide emission with varying load under constant speed of 750 rpm under the different test conditions. The different test conditions were one with hydroxygen addition and other with hydroxygen and water injection compared with pure petrol condition.

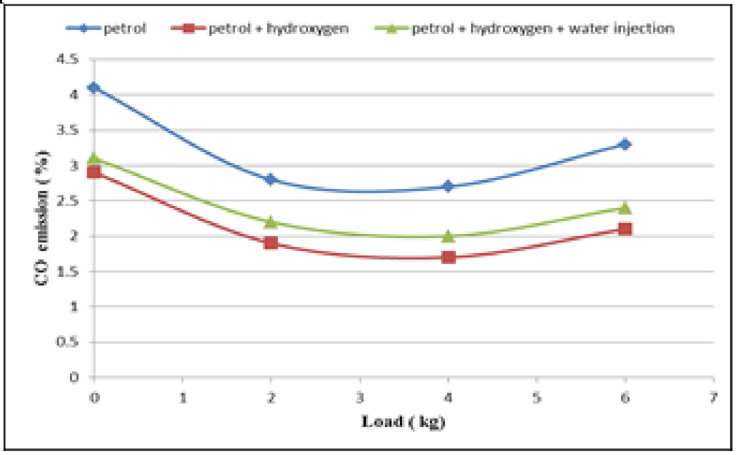

Fig. 6: Variation of Carbon Monoxide Emission with Load

From the graph it can be inferred that the CO emissions were decreased at all engine loads. Decrease in CO emissions was more when hydroxygen addition was employed than with hydroxygen and water injection. Hydrogen is a carbon free compound and thus when it is mixed with gasoline, the amount of carbon in fuel reduces and thus CO emissions were decreased. The high flame speed, higher diffusion rate and larger flammability of hydrogen than petrol results in increase in combustion efficiency and due to high cylinder temperature, the oxidation reaction improves and thus efficient conversion of CO to CO_2 but on water injection causes reduction in cylinder temperature and thus oxidation reaction efficiency reduces.

2) THC Emission:

Incomplete combustion of fossil fuel creates hydrocarbon emission. The unburnt hydrocarbon in the tail pipe gas is called Total HydroCarbon (THC). Figure 7 shows the variation in total hydrocarbon emission with varying load under constant speed of 750 rpm under the different test conditions. The different test conditions were one with hydroxygen addition and other with hydroxygen and water injection compared with pure petrol condition.

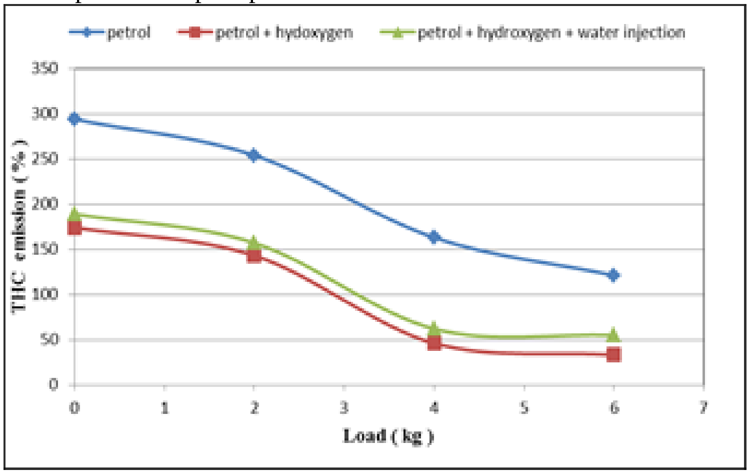

Fig. 7: Variation of Total Hydrocarbon Emission with Load

From the graph it can be inferred that the total hydrocarbon emissions were decreased at all engine loads. Decrease in Total hydrocarbon emissions were more when hydroxygen addition was employed than with hydroxygen and water injection. The amount of hydrocarbon portion in the total fuel is reduced with hydroxygen addition which causes it to reduce the total hydrocarbon emission and the higher flame speed of hydrogen and the involvement of OH radical reduces the amount of unburnt hydrocarbon. Quenching distance of hydrogen is less than petrol and thus the flame can travel close to cylinder wall and thus the amount of unburnt hydrocarbon is reduced. With water injection, the precombustion temperature decreases and thus reduces the cylinder temperature which in turn reduces the combustion efficiency and thus causes an small increase in total hydrocarbon emission from the case with only hydroxygen addition.

3) NO_x Emission:

NO and NO_2 together constitutes the NO_x emissions and the NO_x emission are formed due to the oxidation of atmospheric nitrogen. When nitrogen gas combined with oxygen at high temperature, NO_X emissions are formed.). Figure 8 shows the variation in NO_x emission with varying load under constant speed of 750 rpm under the different test conditions. The different test conditions were one with hydroxygen addition and other with hydroxygen and water injection compared with pure petrol condition.

From the graph it can be inferred that the NO_x emission drastic increases with hydroxygen addition due to increase in cylinder temperature. The increase in cylinder temperature is due to high calorific value of hydrogen than petrol and also due to high flame speed of hydrogen .With the water injection the NO_x emission is decreased from the former case. Due to high heat capacity value of water and high absorption of heat by water, the NO_x emission reduces from the condition of combusting hydrogen only.

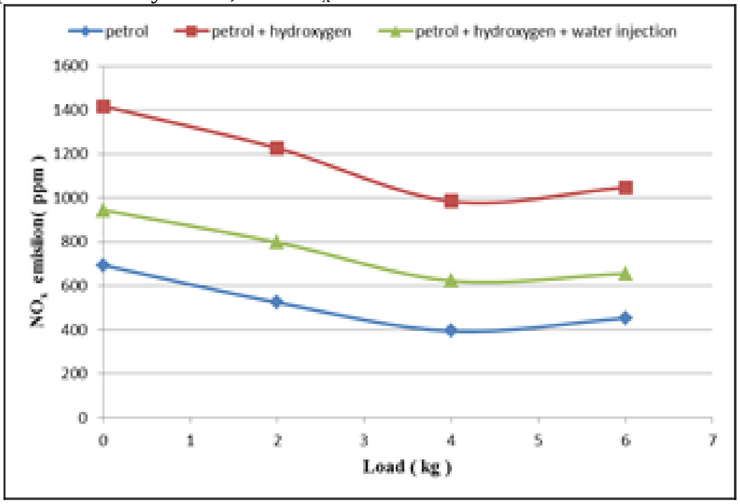

Fig. 8: Variation of NOx Emission with Load

IV. CONCLUSION

The aim of doing this project is to develop an engine that works on a mixture of hydroxygen and petrol with less modification done to the engine. The engine was tested under different load conditions at a speed of 750 rpm. The hydroxygen for the process was developed on board and the mixture of fuel was given to the engine and performance and emission tests were conducted. It was found that with hydroxygen addition the efficiency of the engine was increased and the emissions and fuel consumptions were reduced .Water Injection was given to the engine to reduce the NO_x emission. We can conclude as follows:

- Hydroxygen was produced by advanced electrolysis process using tri-ethylamine as the catalyst and the generation was done on-board and thus eliminating the need for storage.
- The advanced electrolysis method has increased the rate of hydroxygen by 38.368% than conventional electrolysis process.
- With the addition of hydroxygen, there was increase in brake thermal efficiency by 13.8% and decrease in fuel consumption by 11% , on an average of the four loads.
- The combined effect of hydroxygen addition and water injection, brake thermal efficiency was further decreased by 3.23% from the former case and the fuel consumption was increased by 3.89% on an average of the four loads.
- The net increase in brake thermal efficiency when the above two cases were increased by 10.62% and the net fuel consumption was decreased by 17.11% on an average of the four loads and thus with addition of hydroxygen and water injection causes an increase in brake thermal efficiency with reduction in fuel consumption.
- With hydroxygen addition, THC emission were reduced by 57.43% and with the combined effect of hydroxygen addition and water injection, THC emission was increased from the former case by 25.41% and thus the net reduction in THC emission was 32.02% on an average of four loads.
- With hydroxygen addition, CO emission were reduced by 43.32% and with the combined effect of hydroxygen addition and water injection, CO emission was increased from the former case by 11.45% and thus the net reduction in CO emission was 31.86% on an average of four loads.
- With hydroxygen addition, NO_x emission were increased by 129.87% and with the combined effect of hydroxygen addition and water injection, NO_x emission was decreased from the former case by 36.86% and thus the net reduction in NO_x emission was 93.06% from that with hydroxygen addition only on an average of four loads.

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