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Research Article

Performance and Gaseous Emission Investigation of Low Powered Spark Ignition Engine Fueled with Gasoline and Hydroxyl Gas

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Abstract: Hydroxyl gas (HHO) has recently been familiarized to the auto energy sector as a new source of energy. The objective of this work was to investigate a simple HHO and gasoline engine to evaluate the effect of hydroxyl gas addition, as an engine performance improver, into gasoline fuel on engine performance and emissions. HHO is a mixture of mono-atomic oxygen (O) and di-atomic hydrogen (H_2) that is produced by electrolyzed conversion of water (H_2O) in the presence of an active catalyst. Due to high reactive and burning property, it increases the combustion efficiency of gasoline engine when mixed and burnt with gasoline fuel. The HHO gas kit was installed with internal combustion engine, performance analysis and emission analysis has been done by using gasoline and gasoline-HHO separately on the engine. Furthermore, the CO, HC, CO_2 and NOx emissions were measured using exhaust gas analyzer (EMS-5002). Furthermore, the effect of HHO co-burning with gasoline on engine efficiency and environment are discussed. An Experimental investigation is conducted on a 70-cc, four strokes, air cooled, single cylinder internal combustion engine. After investigation, the Engine power was enhanced by approximately 12.2% with significant reduction of specific fuel consumption (SFC) by approximately 37.5% and overall efficiency (η_o) has been increased to 41.5%. Furthermore, unburnt HC concentrations, CO_2, CO and NOx have been reduced by approximately 39.9%, 38%, 53% and 21% respectively.

Keywords: HHO, emissions, internal combustion engine, specific fuel consumption (SFC), brake power

1. INTRODUCTION

Since the last two decades, global warming has raised as one of the key issues for world habitants. Research has shown that increase in exhaust gasses concentration into the atmosphere is major reason of global warming [1]. Automobiles and industrial plants are the main sources of exhaust gasses emissions. Since oil combustion have been utilized to generate power as a source of energy, all regulated pollutants of combustion or simple emissions came out of an engine. The increase in level of pollutants has forced political leader and lawmakers to apply certain clean emission requirements that must meet for automotive energy sector. The emission sampler, which is called as emission gas analyser measured five diverse types of emission gases, i.e. hydrocarbons (HC), CO_2, CO, O_2, and NOx [2]. Hydrocarbons (HC) which is known as unburnt fuel that comes out with exhaust due to poor combustion causes smog [3], which is proportionally increased with the ratio of hydrocarbons in exhaust gases [2, 3]. CO_2 and CO are well-known exhaust gases, referred as carbon-dioxide (CO_2) and carbon monoxide (CO), respectively. Exponential increase in CO_2 level in the atmosphere is causing greenhouse effect and global warming. CO is odorless gas, which is produced due to improper burning can cause human death by holding the O_2 from the human body. O_2 referred as oxygen, obviously good for our environment measured in unburnt gases of exhaust, provide a

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better understanding of combustion characteristics and engine air/fuel mixing performance [4]. Oxides of Nitrogen (NOx) are other types of bad emissions usually produced in compression engine under extremely heated and compressed environment that contains nitrogen in it [2-4].

These NOx emissions are generally produced by all types of engines, but these are considerably lower with the use of Exhaust Gas Recirculation (EGR) valve. EGR valve slows down the combustion rate and provides cooling, which significantly decreases the NOx emissions [4]. CO and CO_2 are the performance indicators of the combustion engine, their quantity in exhaust is generally based on the air-fuel ratio in the engine. The NOx and HC's are the key issues of all kind of combustion engines [2-4]. Catalytic convertors at the exhaust stream may clean the majority of these emissions, and need replacement in repeated cycle because of environmental fatigue and stress [4]. Which makes it short term and non-viable solution. Recently, scientists' interest has been shifting towards lowering the fuel consumption and engine emissions. This motivates researchers to investigate alternative and sustainable solutions that should not require any dramatic change in the vehicle as well as in engine design. Among such solutions, using hydrogen (H_2) gas as an alternative fuel which not only enhances the engine efficiency but also produces almost zero pollution [5]. However, this is not a feasible solution in the concept of modern commercialization; building and integrating a system with a vehicle that produces H_2 makes the manufacturing too much expensive [6], which reflects in vehicle price when it comes to market. H_2 blended with other fuels appeared as another option to increase the engine performance and reducing emissions [7-18]. Ma et al. [7] achieved shorter flame development and propagation period by mixing the H_2 with natural gas (NG). This increases the combustion efficiency and reduced the emissions. Since H2 is the lightest and smallest element in nature with high flammability and reactivity, that makes it as a hazardous fuel to be stored. It can easily combust under an atmospheric condition at concentration range ~4% to~74.2% by volume [19].

Difficulties associated with the use of H_2 as a supplementary fuel can be overcome by producing H_2 using electrolysis process of water into hydrogen-oxygen (HHO) mixture at the point of usage. Yadav et al. [20] improved the engine efficiency and lower the emission by integration HHO production system, powered by vehicle electrical system. Al-Rousan and Musmar also achieved a significant reduction in CO_2, NOx, CO and fuel consumption by 20%, 50%, and ~30%, respectively, by integrating a compact HHO generating device with gasoline engine [21, 22] and Yilmaz et al. [34] reported 19.1% increase in engine torque, a reduction in specific fuel consumption (SFC), HCs and CO emissions with averages of 14%, 5%, and 13.5%, respectively using HHO in compression-ignition (CI) engines. However, these outstanding studies were done using large size and high-power engines. Considering the facts of low earning (i.e., US $ 2 per day or less) socioeconomics [24] and environmental problem [25] in Pakistan today, where two-wheeler industry remained as a major growth driver [26]. This was due to the demographic shift toward urbanization, which exponentially increases the emissions in the environment [27]. This environmental degradation demands fuel efficient system with low emissions for sustainable development.

The main objective of this experimental investigation was to deal with the integration of HHO generating system with 70cc spark ignition engine (Atlas Honda, Pakistan), and introduce some advantage of HHO while maintaining the engine specification. This was achieved by introducing HHO generating system according to engine requirement and installed alongside engine. There is more to be learned regarding the use of H_2 or HHO in gasoline engines. The goal is to emphasize the great qualities they offer such as increased efficiency, peak pressure, and alleviating the drawbacks of higher NOx and reduced mass of the cylinder charge.

2. MATERIALS AND METHODS

2.1 Description of System

The specifications for gasoline engine used in this study are shown in Table 1. Present investigations were made on a gasoline engine, (table. 1 showing specifications). In order to operate the engine on the

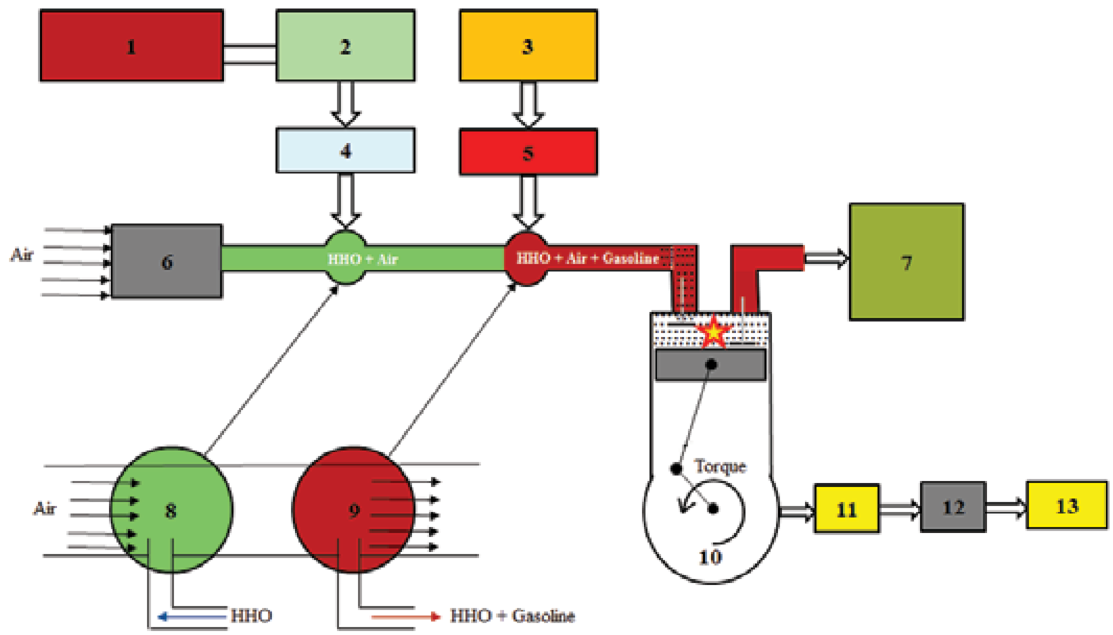

Fig. 1. Schematic of experimental set up. 12 Volts battery (1) HHO Production Unit; (2) Scaled Gasoline Tank; (3) HHO Measuring Meter; (4) Carburetor; (5) Air Filter (Paper-type EAC-HD-024); (6) Exhaust Gas Analyzer; (7) HHO Supply Stream; (8) Two-phase Mixture Stream; (9) 70-cc SI Engine; (10) Dynamometer Absorber; (11) Black Box; (12) Data Processing Computer (13).

Table 1. Spark ignition engine specifications.

Manufacturer	**Honda Atlas Limited (pvt)**
Type	70-cc, SI Engine
Stroke and Bore	41.4 x 47.0 mm
Compression Ratio	8.8: 1
No of Cylinders	1
No of Strokes	4
Maximum Speed	1700 RPM
Cooled by	Air
Start with	Kick

mixture (C_8H_{15} + HHO), a specially designed HHO production cell was used as an add-on for the set-up. A schematic diagram for the experimental setup is also presented in Fig. 1. Fig. 2 shows the placement of engine which is mounted on a specially designed trolley. The supply of desired quantity in SCHF of HHO was carried out by using production cell and metering device. The DC current of 12 Volts was supplied to production cell by using a battery

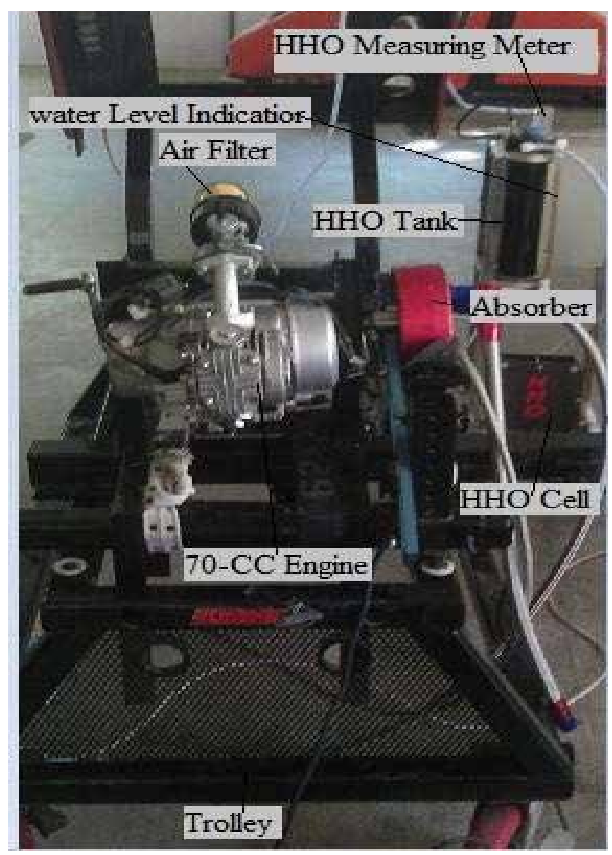

Fig. 2. Actual investigation setup.

(Osaka Pakistan Accumulators). In order to generate the desired amount of HHO, the maximum voltage, i.e., 24 volts DC is provided by a transformer (220 volts) joined with the potential divider. To collect and analyze the data, a dynamometer coupled with Dyno-Max-2010 and engine shaft was used. Dynamometer specifications are as per following: Max Torque of 200 feet-pound and Capacity of 30 hours' power with trade mark Dynomite TM and Dynamometer Land & Sea Manufacturer.

The exhaust gases were analysed using Exhaust Gas Analyser (EMS-5002). By connecting engine with dynamometer through engine shaft, the power of the engine can be provided in desired units i.e. Horse power (HP). The normal operating range for a conventional SI engine using gasoline is $12 \leq A/F \leq 18$ ($0.083 \geq F/A \geq 0.056$) [28]. The analysis of exhaust gases was conducted (300-850 rpm) to ensure the impacts of HHO and gasoline mixture on environment.

2.2 Hydroxyl Fuel Production

Disintegrated hydrogen and oxygen molecules formed due to electrolysis of water (H_2O) into the catalytic environment based on following Eq. (1). A small quantity (10%) of potassium hydroxide (KOH with 56.10 gram) was dissolved in distilled water for the initiation of the reaction. Current flows from negative terminal (cathode) to positive terminal (anode) of battery, on cathode, bubbles of hydrogen (H_2) gas gather at cathode while the oxygen (O_2) collected at anode. In H_2O, two H_2 and one O_2 molecules are present, so double quantity of H_2 bubbles are generated at cathode as compared to O_2 bubbles generated at anode.

$$\text{HHO} \xrightarrow{\text{Varying Curren}} \text{HHO (Hydroxyl Gas)} \qquad (1)$$

(1) HHO production system used in this study is illustrated in Fig 3a. It includes separation tank which supplies a continuous stream of water to maintain the inside temperature (90˚C - 110˚C) of HHO cell and provide hydrogen gas continuously. Disintegrated mixture of hydrogen–oxygen containing water droplets generated in HHO cell, was stored in the separate tank.

Fig. 3 (a). HHO production unit.

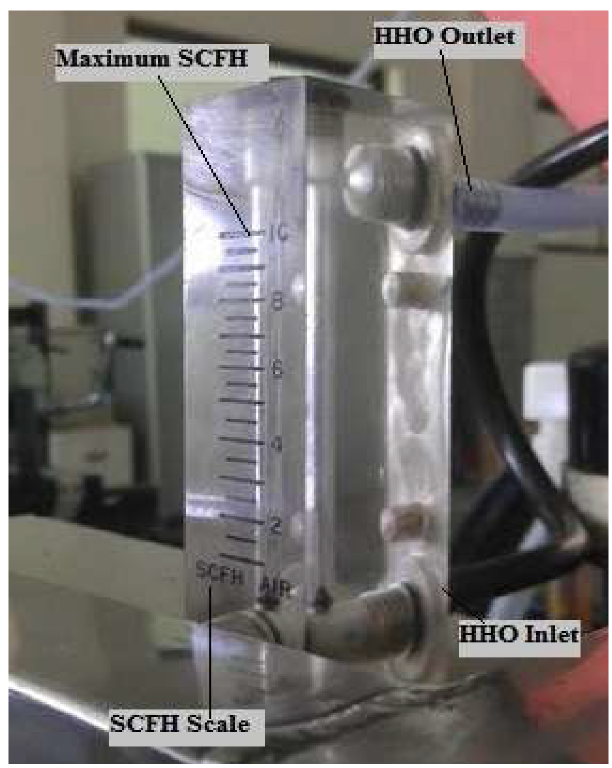

Fig. 3 (b). HHO flow meter.

$$2H_2O \longrightarrow 2H_2 + O_2 \quad (2)$$

Water droplets will separate and fall to the bottom of the tank with the rest of the water, while hydrogen and oxygen gases are directed to the engine intake manifold. The HHO flow rate was measured by calculating the water displacement per time according to the setup shown in Fig. 3b. The HHO gas leaves the separation tank and flows into the water open pool pushing the water down of the inverted graduated cylinder. The volume of gas collected in the graduated cylinder per unit of time was measured as the HHO flow rate. Therefore, the cell productivity can be calculated from the following equation:

$$\text{HHO productivity} = \frac{\text{Volume}}{\text{Time}} \quad (3)$$

Decomposition of water into hydrogen and oxygen was made possible by passing current through the electrolytic solution using electrodes. Next, the combustible gases were allowed to pass through the internal combustion engine to get increment in power and efficiency. In order to produce HHO, a constant volume of one litter of water should be mixed with the molecular weight of electrolyte. To control the HHO production cell, a battery with voltage of 12-V was applied. As by the adjustments on transformer and potential divider, a varied voltage can be applied, therefore by applying voltage variable from 0 to 9, the desired amount of HHO was generated. The measurement of generated HHO was carried out in SCFH by using gas flow meter with max capacity of 10SCFH. The generated HHO was then fed to hose pipe which exist in-between carburetor and air filter. The estimated values for air to fuel ratio for C_8H_{15} and mixture (C_8H_{15} + HHO) were 14.529 & 12.731 respectively. At start, the engine was controlled by using gasoline only. The mixture (C_8H_{15} + HHO) and gasoline was used by changing value of HHO from 2-SCFH to 4-SCFH. For the mixture (C_8H_{15} + HHO); the reported average was 3 runs. The cell productivity was tested without being connected to the engine with 2 different catalysts, KOH and NaOH, to find the best electrolyte with the best concentration experimentally. The calculation was done based on the following equation:

$$mH_2 = \frac{V}{\text{Kmole}} \times M \quad (4)$$

V: Volume of hydrogen gas collected = 1/9 displaced volume (Vd) of the cylinder.

V / Kmole: Volume occupied by one Kmole = 22.4 m^3/ Kmole

M: Molecular weight of Hydrogen gas

Energy gained = mH_2 x $LHVH_2$

Where, LHV of H_2 = 121,000 KJ/kg

HHO production unit efficiency per cell

$$= \frac{\text{Energy Output}}{\text{Energy Input}} \quad \frac{\text{Energy Output}}{\text{Energy Consumed}} \quad (5)$$

3. RESULTS AND DISCUSSION

Hydroxyl gas having one part of oxygen makes it more combustible than cylindered pure hydrogen. Experimentation has been done for different current-voltage combinations, selection of catalyst and its quantity for HHO generation and on varying several engine parameters. Electrolytes, Na_2CO_3, NaOH and KOH has been investigated. KOH was selected as it produced a better quantity of HHO as compared to other two electrolytes. Results depict decrease in water freezing point and variation in HHO production quantity with changing voltage. Stoichiometric combustion reaction having 70 % gasoline and 30 % HHO by volume was investigated.

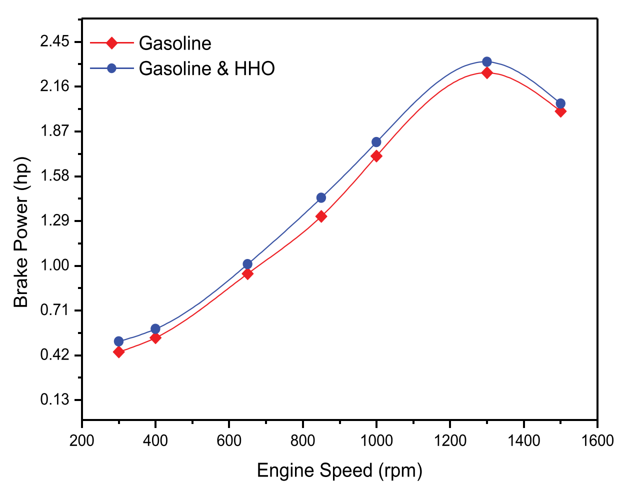

Fig. 4. Variation of brake power with engine speed.

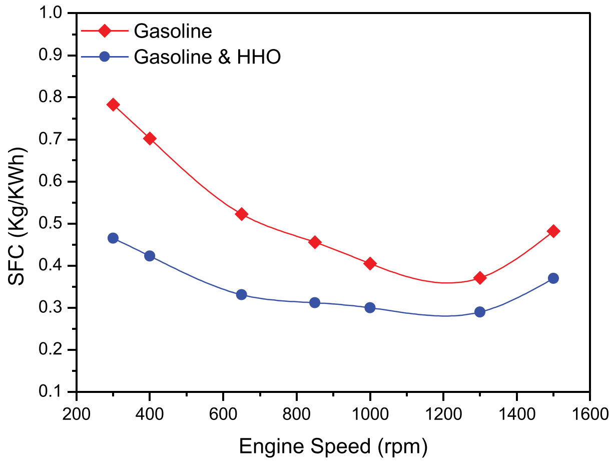

Fig. 5. Variation in BSFC with rpm.

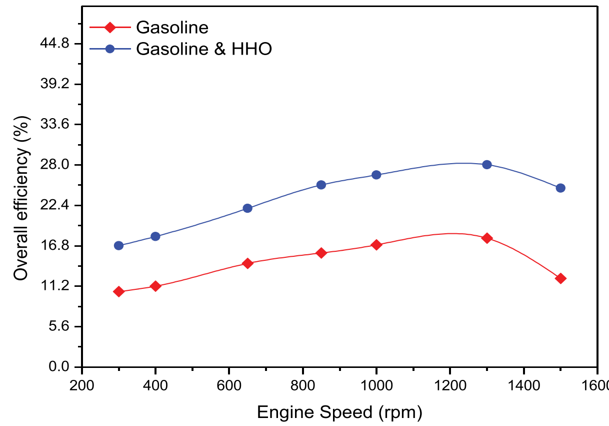

Fig. 6. Variation in overall efficiency with rpm.

$$(0.7C_8H_{15}+0.3HHO)+8.225(O_2+3.76N_2)\rightarrow 5.6CO_2+5.55H_2O+15.463N_2 \quad (6)$$

Hydroxyl gas-air mixture gets mixed with a C8H15 in carburettor and is infused in the engine. Air to fuel ratio is from 12 to 14 for this mixture. The Fig. 4 represents variation in brake power with and without HHO, with respect to engine rpm that is varied from 300-1500. It is clear from the graph HHO co-combustion with gasoline has more brake power than gasoline combustion. With the increment in torque and compression ratio, brake power of engine is also increased. While comparing the compression ratios of the hydro-carbonic fuels, the mixture engine has greater value as compared to gasoline engine alone. Finally, the brake power of the engine was improved. Power of engine is directly affected by the Calorific value. Calorific value has also termed as burning value or heating value. Engine with higher calorific value is assumed to be more powerful. The Calorific value of hydrogen is three times of gasoline. It is noted that HHO gas improves the ignition process through increasing engine thermal efficiency and lessening the brake specific fuel consumption. Comparing HHO gas to commercial gasoline fuel, HHO is enormously effective in terms of the chemical composition of the fuel. Oxygen and hydrogen exist in HHO as two atoms per ignitable unit with self-governing clusters, while a gasoline fuel contains thousands of bulky molecules of hydrocarbon. This diatomic arrangement of HHO gas (O_2 and H_2) results in well-organized burning because the atoms of hydrogen and oxygen interact directly deprived of any ignition propagation delays due to the reaction of surface travel time. On appropriate combustion, its flame front flares through the cylinder wall at a much greater velocity than in normal gasoline/air combustion. The unconfined heat of HHO enabled breaking of the gasoline molecules bonds and hence enhancing the reaction rate and spark speed and then combustion efficiency is successfully improved. Due to above mentioned reasons the HHO + Gasoline engine was more powerful as compared to gasoline engine alone. Brake specific fuel consumption (BSFC) can be determined by dividing fuel flow rate with the power output of the engine and its measuring unit is kg/KWh. It also has inverse relation with the engine brake power, for example: By the increase in engine power the brake specific fuel consumption should be decreased. In the current study, a remarkable reduction in brake specific fuel consumption of engine has been noted by the increase of the brake power. By the average of 37.5% of BSFC has been reduced with increase just in the brake power average by 12.2 %. This reduction was only due to the less fuel consumption rate (kg/hr). Because it has a direct relation to the fuel consumption rate; in other words, by reducing fuel consumption rate, BSFC also reduces. It is additionally noticed that introducing HHO gas to the fuel/air blend has a positively effect on the octane rating of gasoline. Consequently, the engine compression ratio can be raised and more improvement in the efficiency can be achieved. In addition, the ignition advance could be improved to maximize the engine torque without knocking of the engine. Fig. 5 clearly represents that fuel reduction is reduced by 37.5% on average when HHO-gasoline mixture is burnt as compared to the

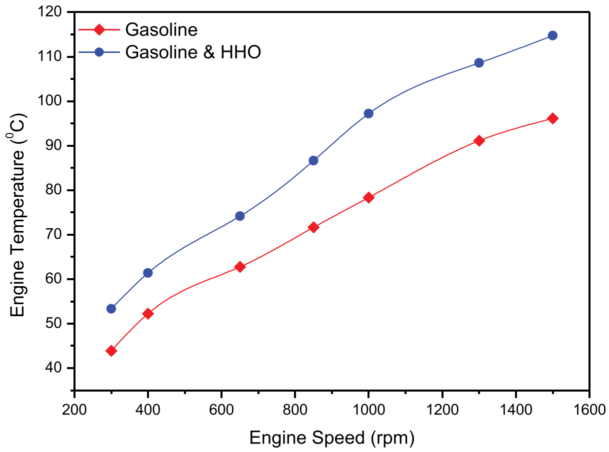

Fig. 7. Variation in temperature with rpm.

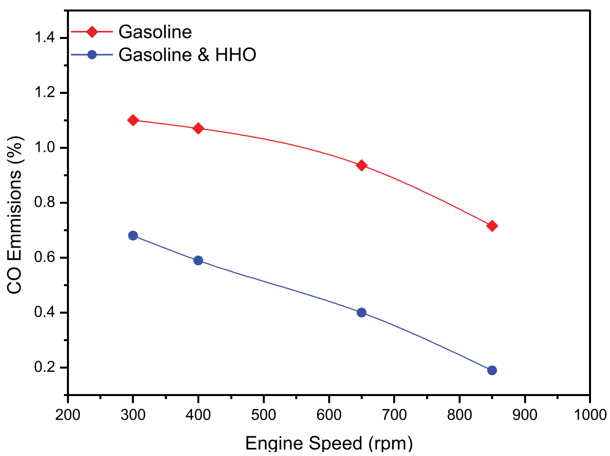

Fig. 9. Variation in concentration of CO with rpm.

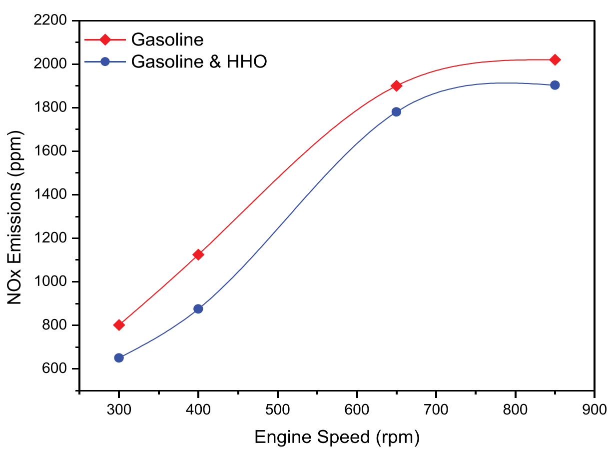

Fig. 11. Variation in concentration of NOx with rpm.

running engine on simple gasoline. Fig. 6 shows that the overall efficiency (ɳo) increases around 41.5% when HHO gasoline mixture is combusted in the engine as compared to a simple gasoline engine.

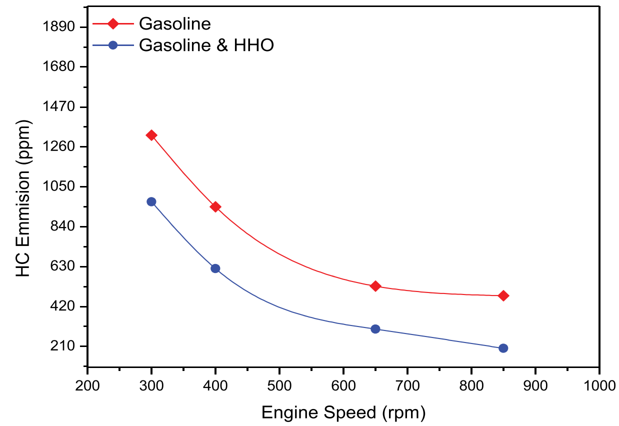

Fig. 8. Variation in concentration of hydrocarbons with rpm.

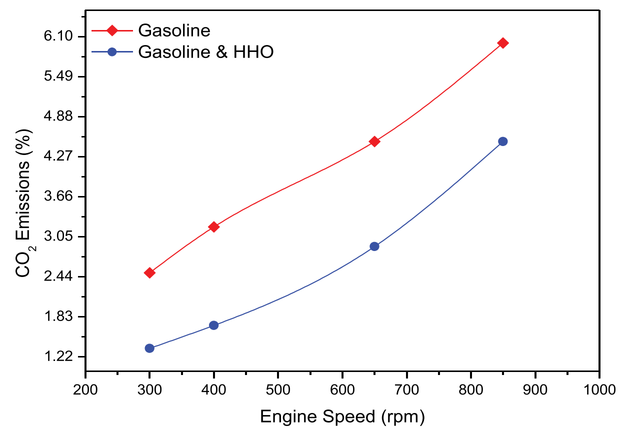

Fig. 10. Variation in concentration of CO_2 with rpm.

$$\text{Overall Efficiency} = \frac{\text{Energy output in KWh}}{\text{Energy input in KWh}} \quad (7)$$

It can be observed from Fig. 7 that engine has 14.5% more outer temperature when operated with HHO Gasoline mixture and it is increasing with increase in rpm. Further analysis shows that due to the high calorific value of HHO i.e. 121MJ/Kg as compared to gasoline i.e. 43MJ/Kg, the thermal efficiency of the engine has been increased by 20% approximately. The exhaust gas analysis of 70-cc motorbike engine operating with both gasoline alone and mixture of HHO + gasoline has been performed successfully. For this reason, exhaust gas analyser has been utilized. On the silencer exhaust, the sensor of the gas analyser was inserted for the calculations of exhaust gases. So, for this experimentation the gasoline and HHO engine was run in the range of 300 RPM (revolutions per minute) to 850 RPM. The hydroxyl gas utilized for this investigation is just 2- SCFH (Standard Cubic Feet per hour) and 4- SCHF. And 1-SCHF= 0.47 LPM (Litters per minute). For rich mixture Φ is more prominent than unity and for lean mixture, it is not as much as unity and for stoichiometric response, Φ is equivalent to unity. (Φ is called as Equivalence Ratio). Carbon monoxide (CO) is produced from the inappropriate oxidation of hydrocarbons; it is formed when there is a lack of oxygen to make carbon dioxide, for instance, when operating an IC-Engine in an encased space. At the point when the analysis was figure out on this mixture to figure the rate of CO, 53% reduction has been done as explained in Fig. 9. Flue gas analysis was also done that represented 39.9% reduction in HC concentration and 38% reduction in CO_2 concentration as compared to a gasoline engine.

The reduction in the hydrocarbon concentrations (Fig. 8) and that of CO_2 (Fig. 10) is because HHO is not a fossil fuel. It comprises of only hydrogen and oxygen and friendly environment gas. When it is mixed with air in the carburettor some amount of carbon in the air is inducted into the carburettor. So, this amount has been recorded after burning the fuel mixture which was greatly reduced as compared to the other fossil fuels. The comparison of gasoline and gasoline & HHO mixture acquired for Carbon mono oxide investigation is demonstrated in Fig.10. High NOx emission is generally expanded with high flame temperature and surplus air. Bringing HHO into the intake manifold results in dropping the amount of gasoline fuel which primes to lean mixture and hence, subsequent in a reduction in the flame or ignition temperature. Hence, lower NOx emission is achieved as shown in Fig. 11. Hydroxyl gas changes all emission curves downward, since it increases the combustion features and therefore reduces the specific fuel consumption at any speed. The found results from this experimental investigation have a comparable trend as those for reference. [29-35].

4. CONCLUSIONS

In this work, the generated HHO gas was introduced to the air stream just before entering the carburetor of a Honda 70-cc engine without applying load. Analysis of emission and Gasoline-HHO engine performance is made for just gasoline and Gasoline + HHO combination respectively. By comparison of the results found using gasoline & mixture (Gasoline + HHO), we have concluded the following successful results,

- An increase in the combustion efficiency is observed when Hydroxyl gas is used in gasoline engines, which consequently reduces fuel consumption and thereby decreasing the pollution.
- 12.2% gain in Engine power is observed due to the high calorific value of hydrogen than gasoline.
- The reduction in fuel consumption which has been noticed about 37.5%
- Overall efficiency increases around 41.5%.
- An increase of 14.5 ^{O}C in Engine temperature is observed due to the higher calorific value of hydrogen.
- Hydroxyl gas production system can be easily constructed and easily integrated with existing gasoline engines at a low price.
- Concentration of HC was reduced by 39.9%
- Concentration of CO_2 was reduced by 38%.
- Concentration of CO was reduced approximately 53%.
- Concentration of NOx was reduced approximately 21%.

It is recommended for the future work to study the effect of load on SI engine and the effect of both ignition advance and compression ratio on the engine performance and emissions with incorporating HHO gas into the intake manifold of gasoline engine.

5. ACKNOWLEDGMENTS

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