INVESTIGATION ON MULTI-CYLINDER S.I ENGINE USING BLENDS OF HYDROGEN AND CNG

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Abstract

Blending of hydrogen to enhance the combustion properties of CNG during lean burn is investigated. The blends tested were 2, 6, 9, 13 wt % of hydrogen with CNG. Blending is done online to reduce NOx and improvement in performance output. Sequential injection system is used to reduce backfire and improve power output. At 25 % throttle position and 3500 rpm HCNG blends shown 40 % reduction in CO_2, 10.5% reduction in HC and 20.5 % reduction in CO_2 compared to CNG. There was drastic reduction in carbon based emissions in CNG compared to gasoline due to lower carbon content molecular structure. There is 56 % reduction in NOx for blend of 40HCNG and 30 % improvement in brake thermal efficiency compared to CNG. 15 % power drop is observed due to reduce energy content of charge intake. 20HCNG shown optimum condition with reduction in NOx and carbon based emission and no change in power output compared to CNG.

Keywords: *Hydrogen, CNG, Nitrogen Oxides, Advance/Retard, Lean/Rich, EGR*

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1. INTRODUCTION

Due to high thermal efficiency and power density Internal Combustion engines are widely used as transportation and stationary power source. Foreign exchange expenditure for import of crude petroleum, continuously decreased reserves of fossils fuels, the unsteadiness of their prices and the increasingly stricter exhaust emission legislation, put forward the alternative fuels as substitute for the vehicles.

Methane is increasingly used as an alternative automotive fuel due to its higher hydrogen to carbon ratio than gasoline which results in reduced CO_2 emissions. Furthermore, methane has a high octane number which allows higher compression ratios which in turn increases the maximum achievable thermal efficiency. There are other advantages, among them reduced cold-start and low temperature emissions and compatibility with lean-burn technology.

CNG due to its potential for low PM and carbon based emissions it is looked upon as best alternative fuel.

Blending hydrogen with some amount of natural gas is an effective and applicable way to enhance the combustion of CNG. Increase in flame speed and reduction in ignition energy, which are beneficial to engine efficiency and combustion stability, could both be achieved by hydrogen addition owing to hydrogen's relatively fast burning velocity and low ignition energy. There will be improvement in fuel efficiency with HCNG blends due to improvement in combustion with small amount of hydrogen addition into CNG. This is also indicated by better acceleration performance of the engine with HCNG in relation to standard CNG operation. Increasing hydrogen content of the fuel accelerates combustion leading to the efficiency improvements, decrease burn duration and ignition delay, increase in rate of turbulent flame propagation and extend lean operation limit.

Blending methane with hydrogen not only improves the burning rate of the fuel, it is also generally agreed that blending natural gas (which mainly consists of methane) with hydrogen reduces the emissions of CO_2, CO and HC. Basically, NOx emissions increase with increasing hydrogen content. However, NOx emissions may be lowered below levels reached with pure methane using a catalytic converter or EGR, adjusting spark timing or operating the engine in a lean regime.

This research explains how addition of hydrogen to existing CNG fuelled engine can reduce carbon based emission and achieve higher thermal efficiency. It also ensures an early entry of hydrogen into our energy infrastructure.

It increases heat transfer out of the cylinder due to smaller quenching distance and higher combustion temperature. 20% by volume is 7 % by energy content or 3 % by mass. No safety or operational problem during running of vehicle. In stiochometric mixture the laminar flame speed of hydrogen is 5 times faster than that of methane. Pure hydrogen form higher peak pressure 45 bar due to the maximum rate of heat release compared to 20 HCNG form 30 bar peak pressure. To achieve thermal efficiency spark timing has to be advanced in blended fuel compared to pure hydrogen and retard compared to CH_4. 10 to 20 HCNG shows interesting HC emission reduction.

HCNG with EGR drastically reduce NOx emission without penalty on engine performance.

2. LITERATURE REVIEW

Hydrogen burns hotter (2318 K) than methane (2148) but cooler than gasoline (2470 K) based on flame temperature in air. (01)

(02) HCNG blends of 10, 30, and 50 % by volume extended lean limit to 1.82, 2.09 and 2.4 resp. compared to 1.71 for natural gas. Hydrogen addition would lead to higher NOx emissions if spark timing is not optimized.

(03) Blends of 12, 22, 33, 48 % volume shown improvement in thermal efficiency by 20 – 25 % compared to CNG. Optimum blend is between 20-35 % giving best performance. There is rise in acceleration with 33 % hydrogen by volume. Maximum power achieved at stiochometric condition. CO, HC and NOx shown diminishing trend with increasing proportion of hydrogen in HCNG mixture. compared to pure methane hydrogen addition up to 60 % volume lower the partial burn limit from an φ =0.58 to 0.34. 60 % vol of hydrogen reduce 26 % $BSCO_2$, 40 % BSCO, 60 % BSHC and increase in BSNO by 30 %. Hydrogen requires less air on volume basis while largest one on mass basis for combustion. It has highest heating value on mass basis but lowest on volume basis. Since product is H_2O, hydrogen has significant difference between HHV and LHV. Energy heat release by combustion per unit mass of stiochometric mixture is one of the highest.

(04) For 30 % blend of hydrogen shown reduction in NOx below limits (100 ppm) by controlling φ between 0.52 to 0.54. NOx emission of approx. 0.11 gm/kw.hr is readily achieved at all power levels.

(05) hydrogen addition contributes much more to reducing flame development duration whose reduction has greatly positive effects on keeping down cycle by cycle variation than to reducing flame propagation duration. When fixed at MBT spark timing NOx emission also can be reduced by hydrogen addition.

Due to low volumetric LHV, stoichometric of hydrogen and air contains slightly less energy (2913 KJ/m^3) than stoichometric methane /air (3088 KJ/m^3) and stoichometric gasoline/air (3446 KJ/m^3).

Hydrogen stoichometric A:F ratio is higher, hydrogen occupies a greater proportion of volume w.r.t air (0.290) then does methane (0.095) or gasoline (0.018

(06) with hydrogen % BSCO values decreases, CO_2 reduces due to low carbon content, BSNO increases due to increase in peak temperature, BSUHC values decreases & lowest at φ =0.9, BTE increases.

(07) Traces of HC and CO is formed due to burning of lubricating oil in the combustion chamber.

In 1 liter engine cylinder gasoline occupy 17 cc of the cylinder while hydrogen occupies 300 cc i.e. stoichometric mixture of hydrogen air is 0.85 times that of gasoline air. If direct hydrogen fed into cylinder, the heat released is about 20 % greater compared to methane gasoline has smaller real combustion losses and slightly smaller wall heat losses. Fuel conversion efficiency increases with blending methane with hydrogen. Relative error in fuel conversion efficiency for the gases is 0.2 % at most whereas it is about 1 % for gasoline.

(08) for 5 HCNG by volume shown 40 to 50 % reduction in CO, 45 % reduction in NMHC and 20 to 30 % reduction in NOx than neat CNG operation.5 HCNG improves power by 3 - 4 % and torque by 2 – 3 % than CNG. There was 4 % reduction in fuel consumption due to lean burn than CNG. 5 HCNG does not occur the phenomenon of hydrogen embrittlement of engine components.

A 0.8 litre, 3 cylinder 4 stroke computerized water cooled multipoint fuel injection gasoline engine (Maruti 800) was converted to a CNG-gasoline bi-fuel sequential type port fuel injection to operated either with gasoline or CNG by switching between the fuel supplies using an electronically controlled solenoid actuated fuel selector. The specifications of the engine are listed in Table 1 and the schematic diagram of the experimental setup is shown in Figure 1. An eddy current dynamometer and Ni-DAQ data acquisition system were used to program the engine test as well as recording engine performance data.

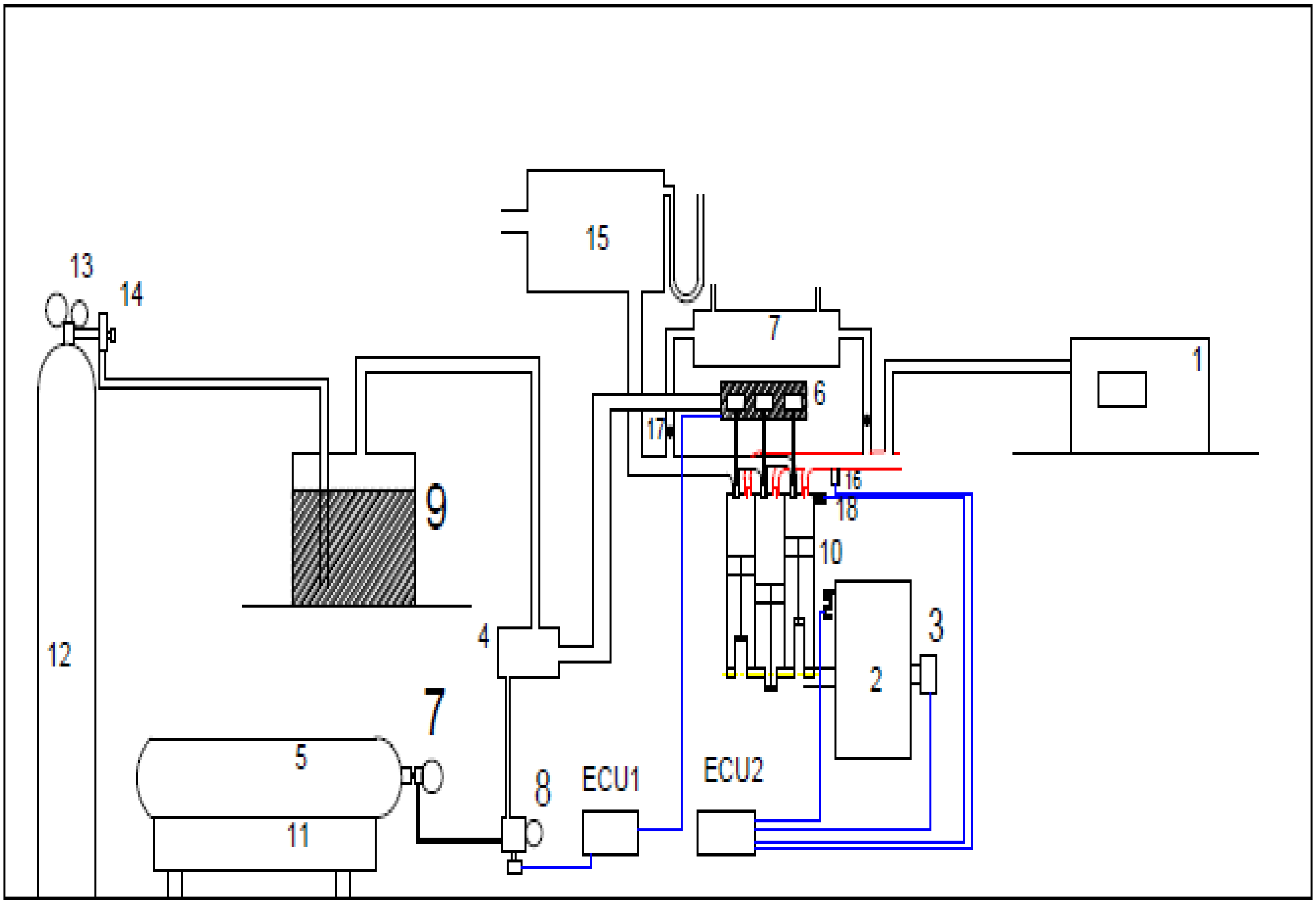
CNG is stored at 200 bar pressure in a tank and its pressure was reduced to 1.5 bar by a 2 stage pressure regulator and a reducer as it is injected through ECU controlled injectors into the intake manifold above inlet valve. A check valve was installed on the fuel system to prevent the backflow of gas. The injection of CNG was controlled by the TAMMONA control software for the engine tuning calibration at different speeds. Gasoline consumption was measured using Alicat mass flow meter. The mass flow rate of CNG was measured using digital weighing balance. A pressure sensor (Kistler type 6125B) was installed to the one of engine cylinder and pressure data was sent to data acquisition system. Exhaust emissions for fuels and blends were measured by AVL 5 gas analyzer. Online blending is used to form the blends of HCNG. Hydrogen cylinder of 75 litres with 2 stage pressure regulator and flow meter is used for blending. Flame trap and flame arrestor is used to avoid chances of back fire. For mixing hydrogen and CNG mixer is used to form uniform mixture prior to injection.

3. ENGINE TEST

Tests were conducted at 25 % throttle (part load 6 Kg) with constant speed 3500 rpm. The four stroke engine is connected to a personal computer based data acquisition system. The system allows simultaneous measurement of all major engine parameters, including torque, flow rates, speed, pressures, temperatures and exhaust composition.

A separate high speed data acquisition system enables measurements of cylinder pressure to measure in-cylinder pressure, heat release and mass fraction burn w.r.t position of crank angle. Although this is a low compression ratio engine for natural gas, with its high octane rating, a direct comparison of CNG and HCNG blends when used in the same engine build was focus of this investigation

4. EXPERIMENTAL SETUP



1 – Exhaust Gas Analyzer (5-Gas)
2 – Eddy Current Dynamometer
3 – Crank Angle Sensor & RPM Sensor
4 – Hydrogen and CNG Mixer
5 – CNG Cylinder
6 – CNG Common Rail with Injector
7 – CNG ON/OFF Valve
8 – ECU Controlled CNG 2 Stage Pressure Regulator
9 – Flame Trap with Pressure Burst Disc
10 – Load Cell
11 – CNG Digital Weighing Balance
12 – Hydrogen Cylinder
13 – 2-Stage Pressure Regulator with Flame Arrestor
14 – Hydrogen Flow Control Valve
15 – Air Box with Orifice and Water Manometer
16 – Exhaust Oxygen Sensor
17 – EGR Flow Control Valve
18 – Piezo-Sensor
19 – Throttle Position Sensor
ECU1 – CNG Gas Electronic Control Unit
ECU2 – Gasoline Electronic Control Unit

5. OBSERVATION AND RESULTS

Fig 1 Shows reduction in power output of the engine due to reduction in charge intake by mass. It is bi-fuel engine specially designed for gasoline. It is observed that as gasoline is in liquid form it occupies less space as compared to gaseous fuel. The reduction in power output can be compensated by using supercharger or turbocharger to increase intake capacity. Also blending hydrogen with CNG is again drop in power as hydrogen occupies more space than CNG due its lower density. It is observed by increase in hydrogen blends by volume there is reduction energy content of the charge which form reduction in power output. HCNG blends accelerate performance compared to CNG. CNG operation reduces power and limited upper speed which are due to lower charge inhaled energy (due to reduced volumetric efficiency) and slower flame speed.

HCNG blends accelerate combustion leading to the brake thermal efficiency improvement, decrease burn duration and extend lean operation limit. As the intake charge of air fuel mixture increases the mixture become lean. There are also more heat losses in gaseous fuel as flame come more in contact with the cylinder walls.

As it is dry combustion there is wear and tear of valves and piston rings. Gaseous fuel engine run hotter than liquid fuel engine for given mass of fuel. Fig 2 shows at 6 wt % of hydrogen there is improvement in brake thermal efficiency, as hydrogen higher flame burning velocity enhances combustion of CNG. Higher blends reduce power output with reduction in brake thermal efficiency. There will be reduction in BTE of CNG and blends compared to gasoline due to higher density of gasoline. It increases heat transfer out of the cylinder due to smaller quenching distance and higher combustion temperature. To achieve higher thermal efficiency in HCNG blends the spark timing has to retard compared to CNG and advance compared to hydrogen. Fig 3 shows there is increase in consumption of CNG compared to gasoline due to more heat losses. For 6 wt % of hydrogen there is reduction in SFC due to enhancement of combustion as compared to CNG.

Pure hydrogen for higher peak pressure due to maximum rate of heat release For the part load condition (6 kg) and constant speed 3500 rpm fig 3. Shows continuous rise in cylinder peak pressure due to increase in flame speed and rise in temperature.
EGR drastically reduce nitrogen oxides emission without penalty on engine performance. . Hydrogen addition would lead to higher NOx emissions if spark timing is not optimized when fixed at MBT spark timing. NOx emission also can be reduced by hydrogen addition. NOx increases due to increase in peak temperature. NOx formations are more at higher speed and load. Euro V norms is more stringent for NOx reduction as it forms nitric acid when come in contact with atmospheric water vapour. For dedicated CNG engine NOx emissions are less than bi-fuel engine. Lean mixture form reduction in NOx emission with sacrifice in power output. Fig 5 shows reduction in NOx with increase in hydrogen wt %.

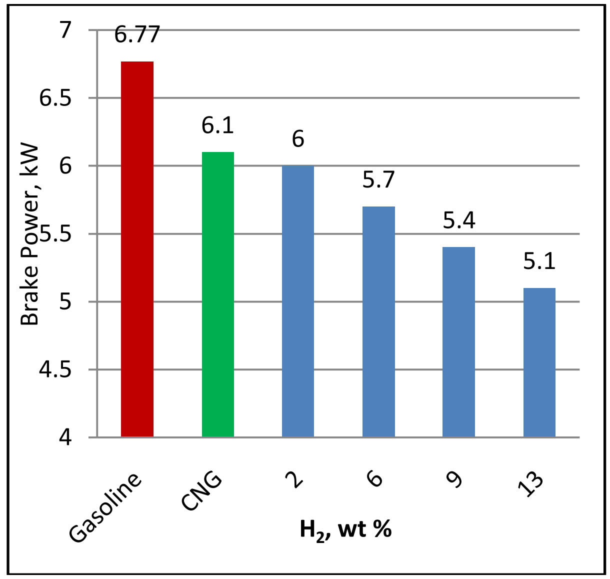


Fig 1: Effects of blending on Power output

There is continuous reduction in HC emissions with increase in hydrogen blends. As hydrogen is carbon less fuel the C/H ratio for blends are less. The increased temperature and enhanced flame speed reduces hydrocarbon emissions.

Due to higher heating value of hydrogen there is increased in combustion temperature which forms increase in exhaust temperature

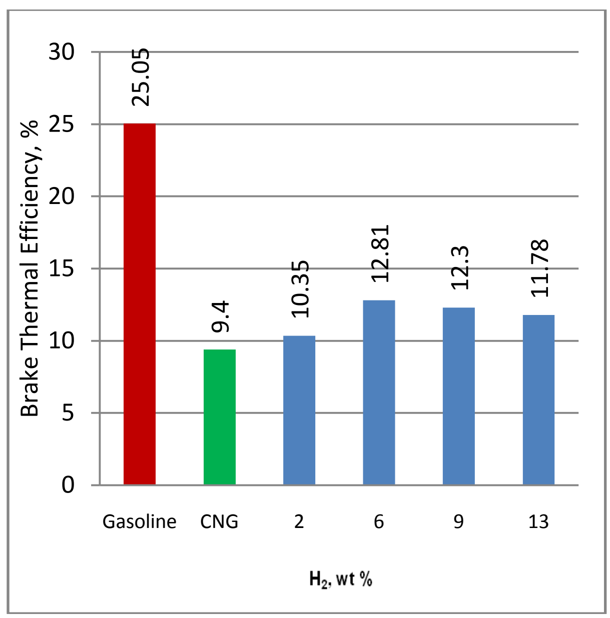


Fig 2: Effects of blending on Brake Thermal Efficiency

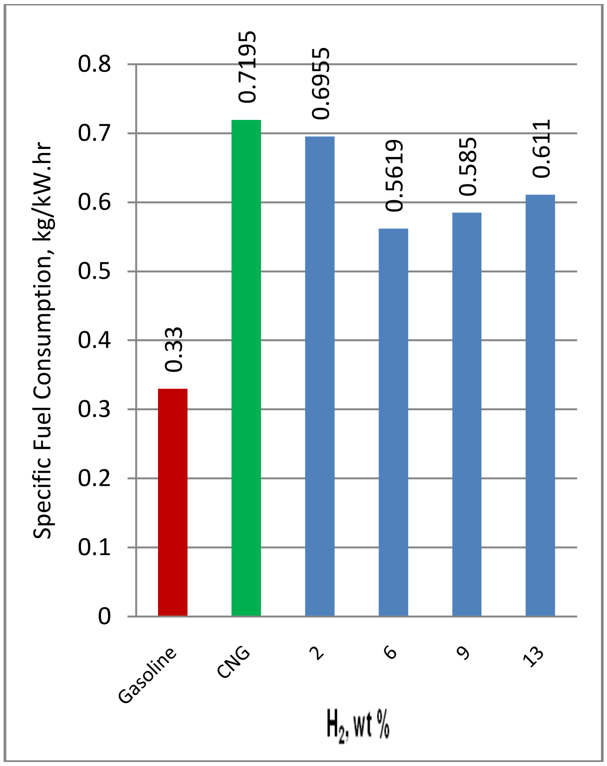


Fig 3: Effects of blending on Specific Fuel consumption

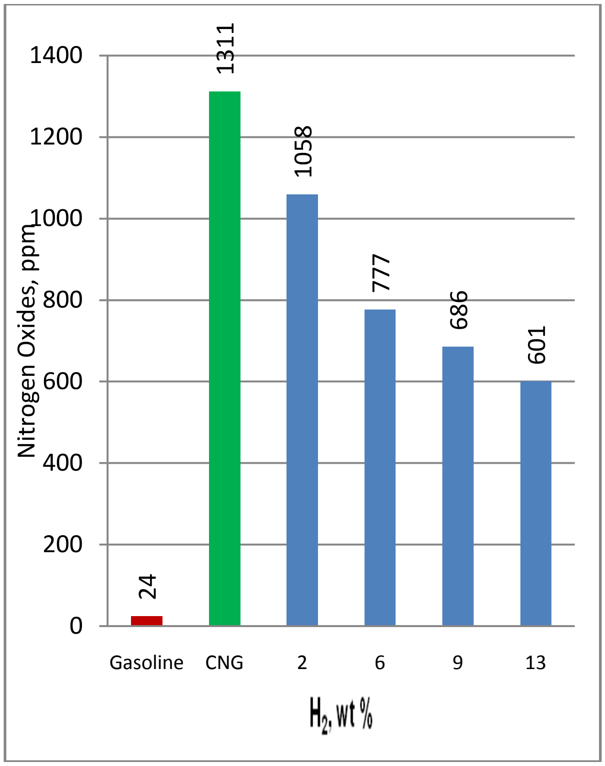


Fig 5: Effects of blending on Nitrogen oxides

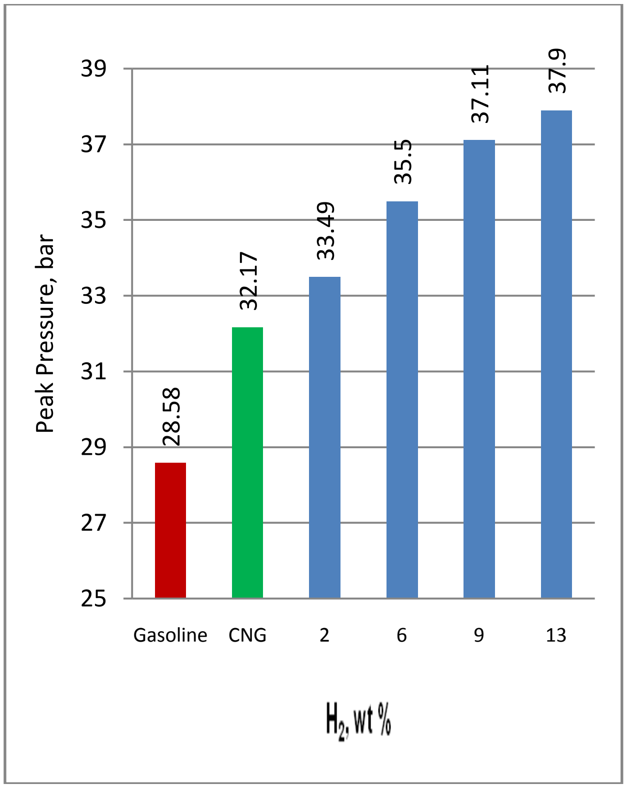


Fig 4: Effects of blending on Peak Pressure

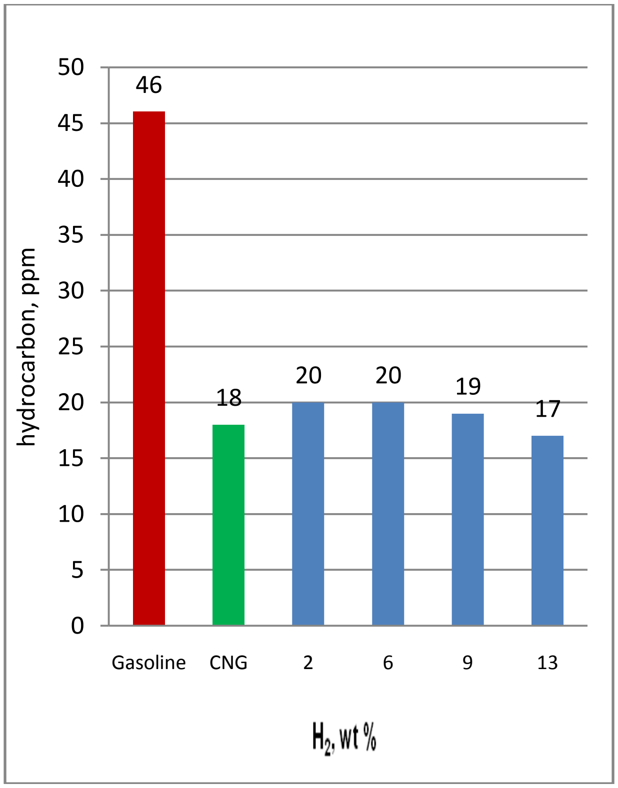


Fig 6: Effects of blending on hydro Carbon.

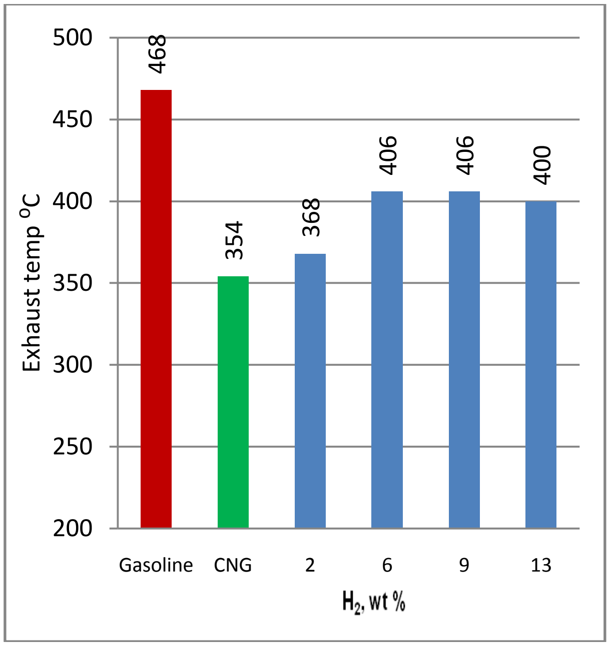


Fig 7: Effects of blending on Exhaust Temperature

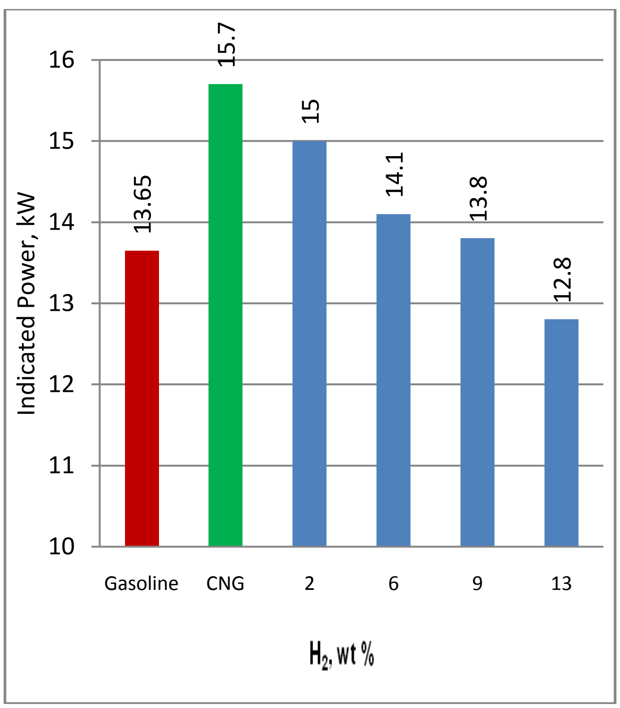


Fig 8: Effects of blending on Indicated Power

CNG operation reduced power and limited upper speed which are due to lower charge inhaled energy (due to reduced volumetric efficiency) and slower flame speed. There is reduction in fuel consumption due to lean burn than CNG. Lower HCNG blend does not occur the phenomenon of hydrogen embrittlement of engine components.

6.CONCLUSION

Hydrogen has strong effects on the combustion of natural gas that can be used to reduce emissions of nitrogen oxides and hydrocarbons. At the small Hydrogen percentages recommended for HCNG, the extra fuel volume is modest. The results obtained by HCNG blending up to 40 lpm to CNG with constant throttle 25 % open shown Reduction in brake power and indicated power. There was continuous increase in exhaust temperature and cylinder peak pressure with hydrogen addition. Upto 30 lpm there is increase in HC and further it reduces. The hydrogen addition shown reduction in CO and NOx emissions with increase in exhaust oxygen. Up to 30 lpm there is improvement in brake thermal efficiency due to hydrogen blending. BSFC was reduced at higher equivalence ratio due to complete combustion. There was a reduction in volumetric efficiency due to reduced density of charge.

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