INVESTIGATION OF PERFORMANCE OF SI ENGINE WITH FUELS - GASOLINE, NATURAL GAS AND H-CNG5 GAS

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Abstract

Increasing need of generation of energy, its effective utilization, reducing fuel consumption, and increasing power outputs has become a major aspect in engine development research. It is beneficial for low speed engines to develop and install Hydrogen-Natural gas blending techniques to improve its performance, to get better operating flexibility in automobiles. Adopting this technology will need a cogent research in hydrogen production, its blending with Natural gas and its delivery management. Hydrogen blended Natural gas can be used as a fuel for an automotives without major modification in the gasoline engine. Real-time research work concludes that the H-CNG fuelled engines are more efficient than petrol fuelled engines from fuel economy, power and emission point of view. In this paper, The SI engine has modified for comparative performance analysis which fuelled with gasoline, Natural gas and H-CNG5 at different operating conditions. The methodology and conditions under which hydrogen can be add to natural gas to improve engine power and to reduce emissions is defined in this research.

Keywords: *Hydrogen, Natural gas, Electrolysis, Emissions*

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1. INTRODUCTION

For this research, hydrogen production unit is prepared based on the splitting of water by water-electrolysis. Small-scale hydrogen gas production plants have only limited commercial availability, but several units are being tested as a part of research. From the experimental work, it is observed that the H-CNG as a fuel is more superior to SI engines from economy of fuel, power gain and exhaust emission acquiescing point of view. The improvement of power and fuel consumption reduction is observed in H-CNG fuelled engine than the gasoline and natural gas fuelled engine.

In particular, the addition of hydrogen to natural gas may have an impact on Safety related to the production, transmission, and end use. It also affects the target performance of the engine, the energy capacity of the Production and delivery system losses and the system components. The contractual conditions, including properties of the gas supplied to engine must be fulfilling for wide range of engine operating conditions. [8]

The scope of the research is to investigate the conditions under which hydrogen can added in natural gas with acceptable modification in engine by maintaining its safety, durability of the system, gas quality management. The methodology is developing to enable the efficient and safe usage of Hydrogen-Natural gas mixture for SI engines. It should be note that, although the objectives of the research concern Hydrogen-Natural gas mixtures, the outcomes are very relevant for defining the conditions under which the existing gasoline fueling system can be use for pure natural gas and other sustainable gases(fuels) with which hydrogen can be blend.

2. SELECTION OF COMPONENTS FOR H-CNG5 FUELLING SYSTEM

2.1 Compressed Natural Gas Cylinder

The CNG Cylinder stores the natural gas under high pressure, is the safest method of using natural gas as an alternative fuel. The idea of natural gas being compressed to 3,600 psi (248 bar) and stored in a vehicle tends to frighten some people away. They're afraid of rupture or explosion, when in fact; the likelihood of either of those occurring is far slimmer with a CNG Cylinder than it would be with a gasoline or diesel tank. CNG Cylinder used for trial is tested as per the standards and it has government approved certification.[12].

2.2 Pressure Regulator (1st Stage Pressure Reducer)

A pressure regulator is a device which acts as a valve which controls the flow of a CNG gas and delivers required pressure. Regulator is use to allow high-pressure gas supply pipelines to be compensate to safe operated pressure. Gas flow meter mounted after pressure regulator to measure flow rate of natural gas. A pressure regulator device's main function is to deliver the desired amount of gas through the storage tank to meet end gas demand. The regulator must compensate delivery of flow as per the engine operating condition. A pressure regulator device has a restricting element and a loading element which brings flexibility in the operation.

The high-pressure regulator has low internal volume. It has fully contained piston. High flow, single gauge type filter positively retained in inlet port. The maximum inlet pressure is 3600 psig (248 bar) the outlet pressure can be vary in the range 0-10 psig through 0 to 1500 psig. Flow coefficient of the valve is 0.06 and 0.20. Maximum operating temperature is 1760F (800C) and can be increase up to 3920F (2000C) with appropriate peek seat. Weight of the regulator with filling valve, nipple and joints is 1.0 lb (0.45 Kg).

2.3 Hydrogen Production Unit

Hydrogen is produce by electrolysis or splitting of water with an electric current. Electricity is lead through water and the water molecules split into oxygen at the anode and hydrogen at the cathode. An electrolytic unit used with an aqueous solution of potassium hydroxide (KOH), which is because of its high conductivity and are referred to as alkaline electrolysis. This electrolytic unit is unipolar. The unipolar electrolyzer resembles in a container and has electrodes connected in parallel. An electrolyte has present between the cathode and anode, which separate the hydrogen and oxygen as the gases have produced, but allows the transfer of ions. Electrolytic unit prepared for the experimentation is currently capable of producing 1 litre of hydrogen per minute. The production rate has regulated by electronic circuit, which has programmed to give number of output values of production rate to ensure 5% Hydrogen-Natural gas blend.[6]

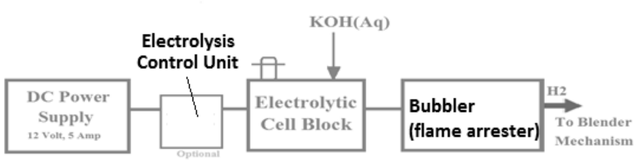


Fig.1. Block diagram of hydrogen production unit

2.3.1 Requirement of Hydrogen Gas to prepare H-CNG5 and Sample Calculations for Quantity of Hydrogen Produced

The test has carried out for natural gas on computerized VCR engine. Let, the fuel consumption (sample) value of natural gas per KW per hour at certain engine operating condition is 1.29 Kg/ KW.h. A 5% of fuel consumption is 0.0645 Kg/ KW.h. A natural gas 0.645 Kg has volume 0.2064 litre at 200 bar in CNG cylinder. Therefore, 0.2064 litre of Hydrogen (per KW, per hour) should be adding to the natural gas to prepare blend of 5%H-CNG. The specific gravity of natural gas is 0.692. Hence, the volume of Hydrogen required per KW, per hour is 206.4 ml. Therefore, 206.4 ml of hydrogen gas have to produce which will be added to natural gas to develop 1 KW power in hour.

2.3.2 Requirement of Electric Current for Electrolysis to Produce Desired Quantity of Hydrogen

Alkaline Electrolysis involves passing an electric current through an electrolyte solution. The ions separated are enforced to undergo oxidation at the anode and reduction at cathode. The amount of hydrogen gas produced is dependent upon the electric current passing through electrolyte, a time of current passing measured in seconds and the number of electrons required to produce or consume 1 mole of the substance.

The current passing through electrolytic cell has regulated by electronic circuit as per engine load demands. The sample calculations have shown for the quantity of Hydrogen produce (at NTP) to prepare mixture of H-CNG5 at load 1 KW. From section 4.11.5, the quantity of Quantity of Hydrogen required is 206.4 ml/hour.

The Efficiency of the alkaline electrolysis has considered being 70% (±2)[8]. Hence, rate of production of hydrogen will be 294.857 ml/hour. If 10% (±1) transmission losses considered [12], rate of production of hydrogen will be 327.62 ml/hour. So the 327.62 ml (or 0.00546 litre/min) amounts of hydrogen have to produce per hour. [3]

One mole of hydrogen is equal to 22.4 litre of H2. [14]
Therefore, moles of H_2
$= [(1 \text{ mole of } H_2)/(22.4 \text{ L of } H_2)] \times 0.00546$ litre/minute
$= 2.4375 \times (10)^{-4}$

The half reaction take place at cathode is [14]

Cathode (reduction) $4 H^+ + 4e^- \rightarrow 2H2$

$4 e^- + 4 H_2O(l) \rightarrow 2 H_2(g) + 4 OH^-(aq)$
No. of moles of e^- =
$[2 \text{ moles of } H_2 / 4 \text{ moles of electron } e^-] \times 2.4375 \times 10^{-4}$
No. of moles of $e^- = 1.27875 \times 10^{-4}$

No. of moles $e^- \times [1F/ 1\text{mole } e^-] = 1.21875 \times 10^{-4}$ F
1.21875×10^{-4} moles $e^- \times [1F / 1 \text{ mole } e^-] = 1.21875 \times 10^{-4}$ F
1.21875×10^{-4} moles $e^- \times [96485 C / 1F] = 11.76$ Coulombs
$1.21875 \times 10^{-4} F \times [96485 C / 1F] = 11.76$ Coulombs
11.76 /60s = **0.196 amps**

Therefore, a current 0.196 amps per minute is required to produce 206.4 ml hydrogen per hour. The addition of hydrogen with flow rate 206.4 ml/hour to natural gas gives 5% HCNG blend. It should be note that, in above calculations the quantity of hydrogen produced is to prepare H-CNG5 to develop 1 KW power. As the engine load changes, the quantity produce to prepare H-CNG5 blend will change accordingly. From the above calculations it shows that, the electrolytic unit is capable of producing hydrogen as per engine demands. The electronic circuit regulates this variation in hydrogen production as per engine loads.

2.3.3 HECU Unit to Ensure Mixtures of 5% Hydrogen with Natural Gas

A Hydrogen electronic control unit (HECU) has designed to regulate rate of hydrogen production as per engine load condition to ensure 5% Hydrogen mixture with Natural gas. It is an important tool to control the electrolysis. A simple production unit can built without electronic unit but that is like having an engine with only the possibility of fix amount of hydrogen added or not maintaining 5 % H-CNG mixture at all. Therefore, the electronic unit is necessary for a controlled electrolysis. [6]

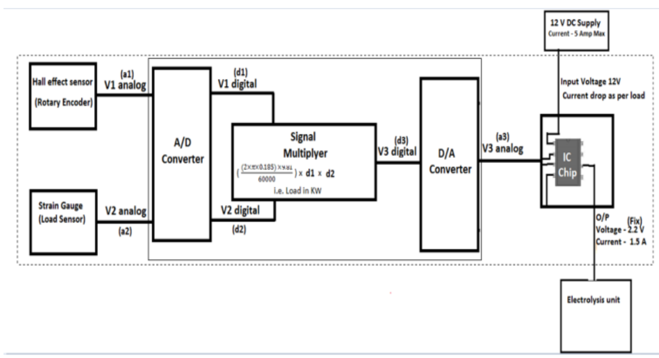


Fig.2. Flow diagram of HECU unit (electrolysis controller)

As shown in fig.2, the input analog signal a1 and a2 has been taken from the rotary encoder (Hall Effect sensor to measure RPM) and a strain gauge (load sensor to measure load in Kg) respectively. These analog signals a1 & a2 have converted to digital signals d1 & d2 respectively by using A-D converter. Further, a multiplier used in the circuit calculates a load output value by multiplying these digital signals d1 & d2 along with constant 0.0001899543 [i.e. (2πR X 9.81) /60000.] where R is eddy current dynamometer arm length. A new output digital signal d3 is generated which is nothing but an actual engine load value (in KW) at that instant (at that engine operating condition). This value d3 again converted into analog signal a3 by using D-A convertor. This output analog signal value a3 read by integrated circuit chip inserted on electronic unit, which has programmed output values of electric current that will pass through electrolytic cell container to produce 5% amount of hydrogen gas. As the output analog signal value a3 changes, the electric current output value will also change as per the value chart programmed in microcontroller ic chip. The chart of 'Engine load & electric current' values used in program is prepared by calculating amount of hydrogen gas required to prepare H-CNG5 and the electric current required to produce that much quantity of hydrogen.

Table 1: Technical Specifications of Hydrogen production unit

Maximum gas supply capacity	1 litre per minute
Electrodes (Anode Cathode)	Stainless steel
Maximum electrolysis voltage	12V , 9A
Electrolysis Voltage and current required max Load (at 1800 rpm	5.2 V, 4.2 A
Electrolyte (1-2 % by mass)	KOH (1m)
Reactor container volume	0.770 L
Water temperature	25oC to 45oC
Overall Dimensions	180 X 200 X 80
Weight	357 gm

2.3.4 Online Mixing of Hydrogen and Natural Gas

For testing, no hydrogen storage tank is use. Storage of hydrogen required high degree of safety precautions. Also, a rate of production of hydrogen is very low. Therefore, hydrogen storage is not feasible. The preparation of hydrogen and blending it with natural gas is direct online. The hydrogen and Natural gas delivery line is merged at blender which is nothing but a part of an engine air hosepipe.[4]

3. EXPERIMENTAL SET UP AND FUEL USED

The test engine is a model year 2010. It is a variable compression ratio, research Petrol engine coupled with eddy current dynamometer. The research work has carried out in IC Engines laboratory, Mechanical Engineering Department, PES Modern College of Engineering, Pune-05. Engine trials has completed at various operating conditions. Engine set up under test having power 4.50 kW @ 1800 rpm. It is single cylinder, four stroke, variable speed, water cooled, Gasoline engine, with Cylinder Bore 87.50(mm), Stroke Length 110.00(mm), Connecting Rod length 234.00(mm), Compression Ratio 10.00, Swept volume 661.45 (cc).

Fig.3. Test Engine -VCR Research Gasoline Engine Set-up

3.1 Hydrogen –Natural Gas Blend as A Fuel

Traditional spark-ignition gasoline engine has disadvantage of the low volumetric efficiency because gasoline exhaust gases occupies a fraction of intake charge that reduces the fresh air into the cylinder, this results in reduction of the power output. In addition, if the engine is modifying for natural gas, it has disadvantage of large cycle-by-cycle variations and poor lean-burn capability. Traditionally, to ameliorate the lean burn capability and burning velocity of flame of natural gas fuelled engine, an increase in flow intensity in cylinder has introduced. The effectual method to resolve the trouble of slow burning velocity of natural gas is to blend the natural gas with the fuel that possesses fast burning velocity. Hydrogen appraised as the unsurpassable gaseous member for natural gas due to its rapid burning velocity, and this unification has expected to improve the lean-burn characteristics and decrease engine emissions. [1]

3.2 Differences between Properties Fuels

The physical and chemical properties of hydrogen-Natural gas blend differ significantly from those of natural gas and gasoline. The following table shows some indicative values at standard conditions of properties relevant for the gas chain from source to end user.[1]

Even the addition of a certain percentage of hydrogen to natural gas will have a direct impact on the combustion properties, diffusion into materials (at high temperature) and the behavior of the gas mixture in air. Therefore, a system designed for gasoline cannot be use without appropriate modifications for Natural gas, H-CNG blend.

Table 2: Differences between properties of gasoline, Natural Gas and H-CNG5 [16]

Sr. No.	Properties	Gasoline	Natural Gas	5 Vol %
1	Volume fraction H2 (Vol %)	--	0	5
2	Volume fraction CH4 (Vol %)	--	100	95
3	Mass fraction H2 (mass %)	--	0	0.705
4	Mass fraction CH4 (mass %)	--	100	99.29
5	Energy substitution (H2)	--	0	1.652
6	Stoichiometric air fuel ratio	15.08	17.19	17.23
7	Mass fraction H (mass %)	13.23	25.12	25.62
8	Mass fraction C (mass %)	86.77	74.87	74.38
9	Lower Heat Value (MJ/Kg)	44.01	51.768	49.11

3.3 Experimental Set up Layout

Flow control valves on hydrogen and CNG lines can operate by the control system assuring accurate blending of fuels. Hydrogen and natural gas can blend to a desirable ratio in terms of volume, mass, or energy equivalent basis.

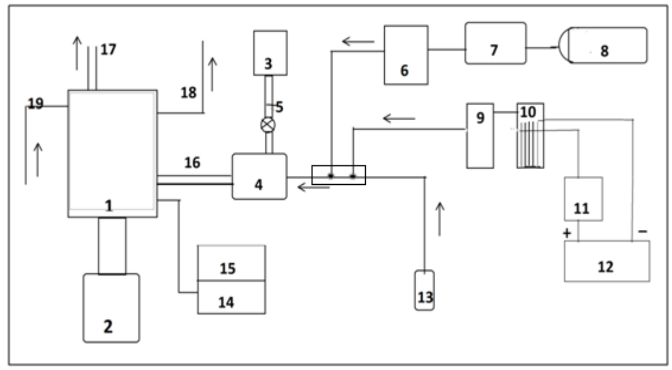


Fig.4 Layout of Experimental Set-up

In figure 4, 1-Test Engine, 2-Eddy current dynamometer, 3-Gasoline tank, 4-Carburetor, 5- Gasoline stop valve, 6-natural gas flow meter, 7-two stage pressure reducer, 8-CNG storage tank, 9-bubbler, 10-electrolytic cell, 11-Electronic unit to control electrolysis process, 12- DC battery (12 V, 9 amp), 13-air filter, 14-Air box, 15-Computer interface, 16-Intake manifold, 17- Exhaust out, 18-Jacket cooling water out, 19-Jacket cooling water in

The layout of the system has shown in Fig.4. The fuel delivered to the engine through a venturi, which has supplied with the fuel mixture at a slight overpressure. The richness is control using a control valve in the supply line. Both natural gas and H-CNG5 mixture can use with this system.

Fig.5. Natural gas cylinder, reducer and supply line

The hydrogen is obtained from electrolytic unit; the natural gas is obtained from the CNG tank at pressure 50 bar to 210 bar. A measured natural gas flow rate at particular engine load supplied as an input signal to the electronic unit (electrolysis controller) the requirement of hydrogen gas is compute and

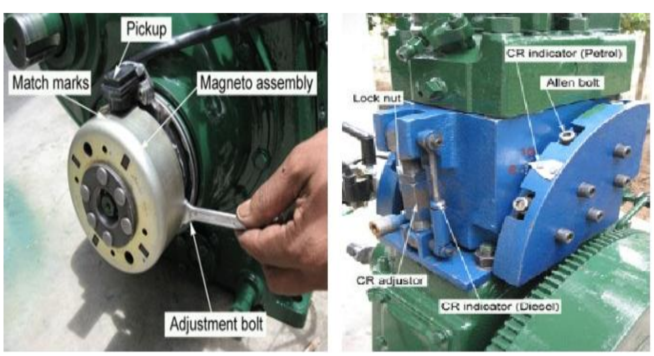
5% volume blend of Hydrogen-Natural gas is maintained. The system described as above is able to provide mixtures with up to 5% hydrogen by volume, due to limitations of production unit and safety aspects regards.

4. MODIFICATION IN ENGINE PARAMETERS REQUIRED FOR PERFORMANCE TESTING

The engine is design for a certain specification set of gasoline, Natural gas and H-CNG5 as fuel. Since the combustion properties change when hydrogen added 5 % by volume to natural gas, this may also affect the performance for that particular engine. Without appropriate modifications to engine, there is an increased probability that flames will extinguished or will 'flash back', system may damage, and there could be a risk of unintended gas releases and an increase in unsafe situations because of adding hydrogen. In addition, an engine life will decrease due to high periodic thermal stresses induced in engine material. The following parameters are necessary to modified for proper functioning of engine with fuel natural gas and H-CNG5.

4.1 Optimization of Ignition Timing

Because of the lower combustion speed of natural gas compared with that of hydrogen, the spark timing has adjusted for optimum engine performance. For blends with small amounts of hydrogen (5% by volume), the engine can be operated without adjusting the spark timing, which will result in only a negligible loss in thermal efficiency. For blends with greater amounts of hydrogen, the spark timing should adjust to maintain efficiency and proper combustion. For testing purpose, spark timing has set at 23^0 btdc. [1]



(a) (b)

Fig.6 (a) Test Engine – Compression ratio adjuster and indicator (b) Test Engine – Spark timing adjustment on magneto ignition system

4.2 Influence of Compression Ratio

The most obvious effect of higher compression ratio is the increased compression temperature and corresponding reduced manifold temperature that is required for a given load and ignition angle. If engine thermodynamic conditions are fixed, increased compression ratio would advance the ignition timing. Normally a lower inlet temperature or a different fuel mixture with a lower fraction of the more reactive fuel compensates. Under normal operation, inlet temperature and fraction of Hydrogen varied to maintain combustion timing at the desired value. However, at a certain maximum load, inlet temperature will decrease to its lowest value, and no Hydrogen is used. This saturation limit depends on compression ratio and occurs early for a high compression ratio.[1]

5. ENGINE TESTING PROCEDURE

Performance plays an important role in the choice of a fuel. H-CNG5 has many advantages when it comes to performance because of the high octane number of hydrogen and better calorific value of mixture. The engine performance is better as fraction of hydrogen added increases.

The trial has taken on Computerized VCR, single cylinder Gasoline engine. The spark timing has set at 230 btdc. The total 48 trials have conducted for fuel Gasoline, Natural gas and H-CNG5. The tests have conducted for different speed ranges from 1200 to 1400 rpm. At this engine speed range, engine can be loaded from no load to 12 Kg. The measurements analyzed with respect to load on engine instead of torque, to make the results less dependent on engine size. The fuel consumption, air consumption, engine cooling, exhaust temperature have measured for above operating conditions. Performance curves have plotted with available results.

6. RESULT ANALYSIS AND DISCUSSION

In the set of trials, a comparative analysis have made between gasoline, natural gas and H-CNG5. It seen clearly, the results for Natural gas and H-CNG5 are quite similar to produce same torque. The only major difference is the ability of H-CNG5 to run leaner, which reduces the fuel consumption.

6.1 Comparative Performance Analysis of Gasoline, Natural Gas and H-CNG5

6.1.1 Brake Thermal Efficiency

Brake thermal efficiency is the relation of final output power with respect to energy supplied. The graph has plotted From Result for engine condition RPM-1600, CR-7, Spark timing 230 btdc and at various loads. In fig.7, it shows that, the thermal efficiency of fuel Gasoline, Natural gas and H-CNG5 increases with increasing load.

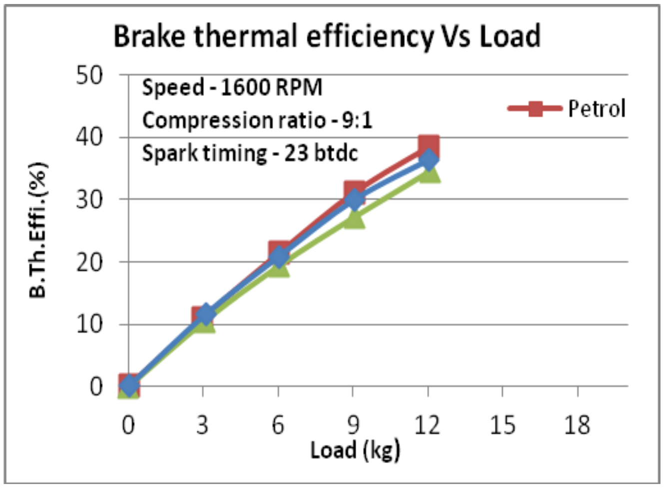


Fig.7. Brake thermal efficiency (%) Vs Load (Kg)

It clearly seen in these curves that in nearly every case; the H-CNG5 fuel has a better thermal efficiency than pure natural gas, which makes it an ideal fuel for high load applications. The brake thermal efficiency of Natural gas at 1600 rpm and 12 kg is 16.41%. For same throttle condition, it increases up to 21.11% for H-CNG5 (increased by 22%). The hydrogen addition allows the lean burn limit to be extending because of the fast burn rate of hydrogen, so the thermal efficiency increases.

6.1.2 Brake specific Fuel Consumption (BSFC)

Brake specific fuel consumption (bsfc) is very important characteristic for comparing the performance of Gasoline, Natural gas and H-CNG5 fuelled engine. Results show the bsfc plotted against the load on engine at various compression ratio. It shows that the bsfc drops, as the load increases in the lower load range at constant speed and nearly levels off as load increases. At lower load conditions, the heat loss to the combustion chamber walls is proportionately greater and combustion efficiency is poorer, resulting in higher fuel consumption for the power produced. At the higher loading conditions, the frictional power is increasing at a rapid rate, resulting in a slower increase in brake power than in fuel consumption, with a consequent increase in bsfc. It has observed during experimentation that, due to addition of hydrogen in Natural gas 5% by volume, the engine operates at leaner side than the Natural gas. It reduces the fuel consumption about 10% to 15% than Natural gas. From the overall analysis of trial results, it concludes that addition of hydrogen (5% by volume) in natural gas increases the rate of burning of the mixture, which shortens the duration of flame propagation which improves the efficiency.

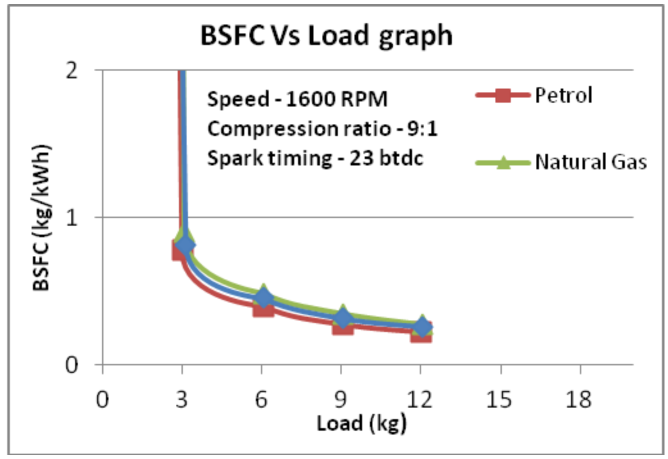


Fig.8 bsfc (Kg/KW.h) Vs Load(Kg)

6.1.3 Brake Mean Effective Pressure (BMEP)

The Brake mean effective pressure (bmep) is the external shaft work done per unit displacement. The bmep increases with the increase in load and engine speed. For H-CNG5, the highest bmep achieved is 4.17 bar at 12 Kg load and 1600 rpm engine speed. The bmep performance results of engine shows that, the brake mean effective pressure increases with increase in engine load when the speed is constant.

The number of trials has carried out at different speed. (These results have not shown in this report due to page limitations.) From that results it concludes that, when a load is constant, the combustion at high speed produces lower bmep than medium speed because a natural gas produce low energy at high speeds due to its lean burn characteristics. Effect of lower energy is causing the lower torque. However, for H-CNG5 fuel it shows that, the bmep is slightly increasing for same throttle condition.

6.1.4 Exhaust Gas Temperature

For Natural gas, the engine should have advance ignition timing than gasoline. It is been observed that the exhaust gas temperature for Natural gas has greater value as compare to gasoline, to produced same power. Retarding the ignition timing is always associated with incomplete combustion and an increase in the exhaust temperature and advancing the Ignition timing decreases the exhaust temperature. For Natural gas, the ignition timing should advance due to its increasing delay period because of its lean burn characteristics. For trial with CNG fuelled engine, the ignition timing was same as gasoline. The ignition timing advancement had not made for natural gas, which means, the engine was working at retard timing for natural gas. As per the results shown in chapter 7, the exhaust gas temperature of natural gas with ignition timing 230 btdc, is increases. When the hydrogen (5% by volume) has added in natural gas, the exhaust gas temperature again increases due to retard in ignition timing. For H-CNG5, the ignition timing should advance more than natural gas because of its increasing delay period due to fast burning velocity of hydrogen.

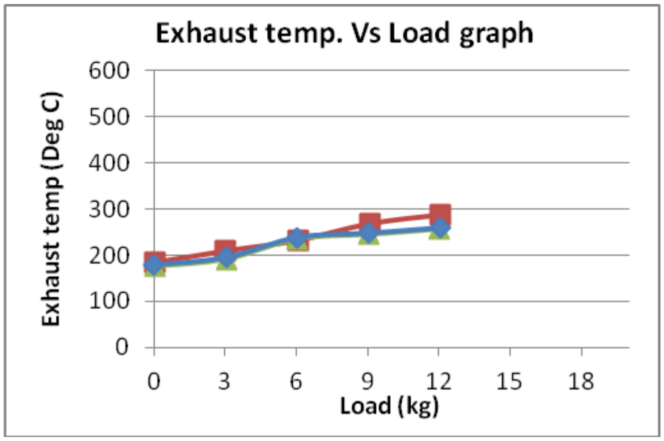


Fig.9 Exuast gas temperature (Deg C) Vs Load(Kg)

6.2 Comparative Emission Results of Gasoline, Natural Gas and H-CNG5

The emission testing has done with fuels Gasoline, Natural gas and H-CNG5. For all operating engine loads, the gasoline emissions are greater than Natural gas and H-CNG5. Whereas, the emission for H-CNG5 is less than Natural gas fuelled engine because addition of hydrogen in natural increases the hydrogen to carbon ratio of fuel, which effectively reduces the carbon based exhaust emissions. The experimental exhaust emission results of optimized Natural gas and H-CNG5 engine has given in Table below. (Graph have plotted at 1600 RPM and for various compression ratios)

Table 3: Emission test results of Gasoline, NG and H-CNG5

	Gasoline			Natural gas			H-CNG5		
	at 9 Kg			at 9 Kg			at 9 Kg		
1600 RP	CO	HC g/KW	NOx	CO g/KW	HC g/KW	NOx	CO g/KW	HC g/KW	NO
CR	0.121	0.564	668	0.116	0.498	432	0.101	0.421	375
CR	0.108	0.521	754	0.098	0.466	572	0.082	0.389	516
CR	0.089	0.492	839	0.076	0.412	698	0.069	0.351	612
CR	0.068	0.448	923	0.054	0.393	754	0.057	0.315	683

6.2.1 Carbon Monoxide (CO)

The graph of CO emissions at different compression ratio has shown in fig.10. The better mixing of fuel with air leads to complete combustion, which helps in reducing the CO emissions. Moreover, since the combustion temperatures are higher with H-CNG5 fuel, the engine runs hotter thereby facilitating better combustion. It observed in the experimental work that the CO emissions have drastically reduced with fuel H-CNG5. There is about 25% reduction in CO emissions with H-CNG5 operation as compared to gasoline and 15% reduction as compare to Natural gas. From the results, it concludes that H-CNG5 is better fuel than gasoline and Natural gas in emission point if view.

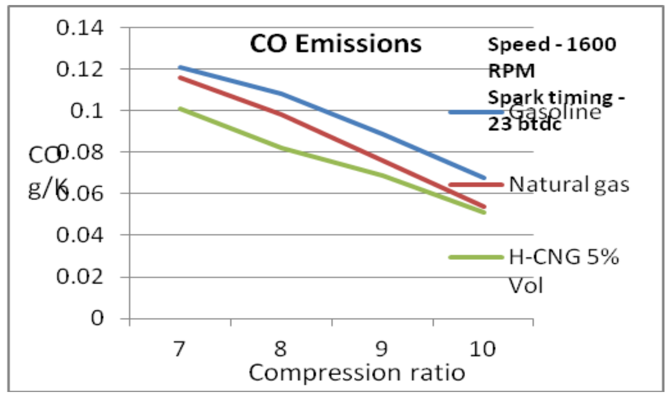


Fig.10. CO emissions (g/ KW.h) Vs. CR

6.2.2 Hydrocarbons (HC)

The H/C ratio of the H-CNG5 fuel is higher. In addition, a tendency of flame quenching becomes less because the cylinder walls and cylinder head run hotter. Due to addition of hydrogen in natural gas, an ignition lag becomes smaller and regular burning period increases, which gives better combustion. Therefore, the HC emissions of H-CNG5 fuelled engine have reduced about 18% than gasoline and 14% than Natural gas.

For all fuels, as the compression ratio increases, an HC emission decreases due to increase in combustion pressure and airflow rate.

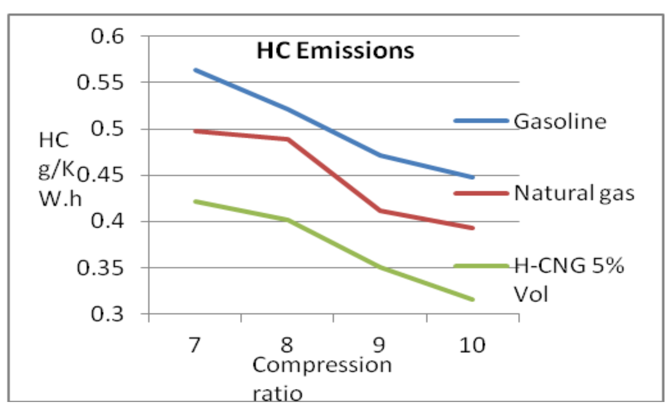


Fig.11. HC emissions (g/ KW.h) Vs CR

6.2.3 Nitrogen oxides (NO_2)

Nitric oxide (NO) and nitrogen dioxide (NO2) are usually group together as NOx emissions. NO has the predominant oxide of nitrogen produced inside the engine cylinder. Principal source of NOx is oxidation of atmospheric (molecular) nitrogen and high combustion temperature. Engine emission tests for various load, speed and CR have conducted with Gasoline, Natural gas and H-CNG5 fuel. The graph of nitrogen dioxide (NO2) against different compression ratio has shown in figure 12. It is observe from the results that NOx emissions have reduced by about 20 to 30 % with H-CNG5 operation as compared to Gasoline.

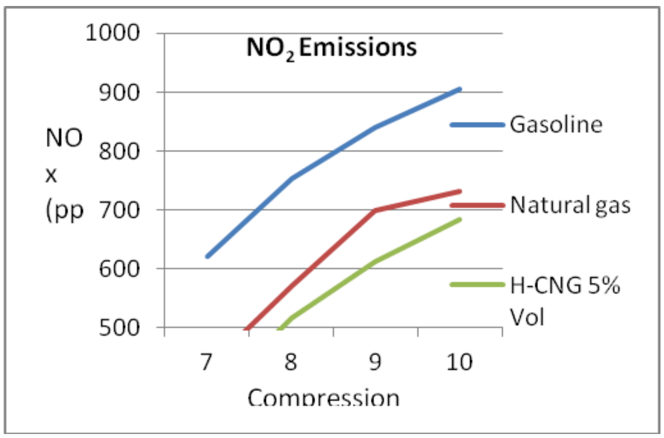


Fig.12. NO_2 emissions (ppm) Vs CR

For all fuels, as the compression ratio increases NOx emissions increases due to comparatively high heat release. However, H-CNG5 NOx emissions lower than natural gas and Gasoline due to increase in the flame speed of H-CNG5 fuel.

7. CONCLUSIONS

The research work about modification in SI engines and its performance analysis in comparison with Gasoline, Natural gas and H-CNG5 has satisfactory outcomes. The scope of research work has giving broad knowledge about engine emission of H-CNG5 as an automotive fuel compare to Gasoline and natural gas. Based on the present experimental research work, the following conclusions have drawn.

- From the results obtained, the Air-Fuel mixture for H-CNG5 has comparatively lean for nearly all range of operating conditions. Therefore, the flame burn velocity of the SI engine has improved by adding 5% hydrogen by volume in Natural gas which burning velocity is higher than gasoline and pure natural gas.
- The engine combustion pressure increases by adding 5% Hydrogen by volume in Natural gas. Hydrogen, which has fast burning fuel, shortens duration of combustion and increases the combustion temperature. This improvement in combustion properties makes H-CNG5 fuelled engines more efficient than gasoline engines from power and fuel economy point of view. The H-CNG5 fuel improves power gain about 14 % as compare to gasoline and about 8% more than Natural gas. The learn burn operation of H-CNG5 fuel reduces the fuel consumption about 12% than natural gas and about 18 % than gasoline fueled engine.
- As compare to gasoline, the engine with fuel H-CNG5 have reduce CO emissions up to 18 % , HC emissions up to 15% for natural gas and up to 20% for gasoline. NOx emissions have reduced up to 20% than natural gas and 30% than gasoline. Thus, the hydrogen blended natural gas, as a fuel is more environmental friendly than other fossil fuels.
- The phenomenon of engine component embrittlement does not occur with addition of 5 percent hydrogen in Natural gas. Also, the thermal stresses induced in the engine components are note so higher, hence no major modifications are anticipated in engine design and existing infrastructure.
- The ultimate goal of the research is to transpose and testing of fossil fuels with neat burning H-CNG blend has fulfilled. The methodology developed by this research is the guide way to further research to make early entry of hydrogen as a fuel into an automobile sector. It should be note that although the objectives of the research concern hydrogen-natural gas 5% blend (by volume), the outcomes are very relevant for defining the conditions under which any of the SI engine can be fuel with H-CNG blends more than 5% (by volume).

The objective of the project that, to study and analyze comparative performance of the modified SI engine with gasoline, Natural gas and H-CNG5 as a fuel is completed and the results are satisfactory. This technology will represent a "bridge" towards the introduction of pure hydrogen as a fuel for automobiles.

Abbreviations and Acronyms

A/F	Air-Fuel ratio
Btdc	before top dead center
CNG	Compressed Natural gas
CR	Compression ratio
HECU	Hydrogen Electronic Control Unit
H-CNG5	blend of 5% Hydrogen by volume with Natural gas
H/C	Hydrogen to Carbon ratio

ACKNOWLEDGMENTS

I take this opportunity to convey my deepest gratitude to my project guide Prof. S. J. Navale and HOD, Prof. S V Chaitanya, Mechanical Engineering Department, AISSMS COE, Pune, who has given me valuable guidance and suggestions at every juncture of need. I am also thankful to HOD, Mechanical Engineering Department, Modern COE, Pune, for providing testing facility in their IC Engines lab.

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