Experimental Study on Conversion of 4 Stroke Gasoline Internal Combustion Engine into Enriched Compressed Natural Gas Engine To Achieve Lower Emissions

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ABSTRACT

In spark ignition engine with gasoline and compressed natural gas as fuel, performance and emissions results were recorded under steady state operating conditions. The engine is run at wide open throttle and constant speed ranging from 1000 rpm to 5000 rpm with 500 rpm increment. On average, we have observed that CNG operation results in 3-12% less Mechanical efficiency compared to gasoline. In terms of exhaust emissions, the results show that HC, CO and CO_2 have got reduced significantly by 40-66%, 54-98% and 28-30% respectively compared to gasoline. Now a days the emission norms are very stringent. Emission standards like Bharat Stage IV (Equal to EURO IV) is implemented in India, in 13 major cities, since April 2010 and Bharat Stage III is implemented nationwide since April 2010. To meet the EURO V norms this can be further modified into Hydrogen Enriched Compressed Natural Gas (HCNG) system by using hydrogen with CNG. This process is carried out to reduce the exhaust emissions at its best and to have the complete combustion of fuel from the beginning itself.

***Key words*:** Bharat Stage, CNG, Emission standards, EURO, Exhaust gas analyzer

I. Introduction

There are currently more than 9 million Natural Gas Vehicles (NGV) operating worldwide, with numbers increasing by more than 35% per year. Most of these vehicles operate on Compressed Natural Gas (CNG), however, advances in gas storage and transport technology are bringing about significant changes in NGV options. According to Brett Jarman[1] the Liquefied Natural Gas (LNG), small scale liquefaction, bio methane (biogas), Hydrogen Methane Blends (HCNG), Adsorbed Natural Gas (ANG) and even synthesized methane hydrates are all available on the commercial horizon.

Compressed natural gas is the most favorite for fossil fuel substitution. As per Semin[2] the new design of the CNG engine injector nozzle holes geometries of the port injection CNG engine can be achieved through increased understanding of the fuel spray process. The objectives of the gas fuel spray simulation of sequential port injection CNG engine using injector nozzle multi holes is to simulate the injector nozzle multi holes injected gas fuel spray effect in combustion chamber of sequential port injection dedicated CNG engine based on variation intake valve lift.

Natural gas is found in various locations in oil and gas bearing sand strata located at various depths below the earth surface. Compressed natural gas is the most favorite for fossil fuel substitution. CNG is a gaseous form of natural gas was compressed, it have been recognized as one of the promising alternative fuel due to its substantial benefits compared to gasoline and diesel fuel. These include lower fuel cost, cleaner exhaust gas emissions, higher octane number and most certainly. Therefore, the numbers of engine vehicles powered by CNG engines were growing rapidly. Natural gas is safer than gasoline in many respects. The ignition temperature for natural gas is higher than gasoline and diesel.

Additionally, natural gas is lighter than air and will dissipate upward rapidly if a rupture occurs. Gasoline and diesel fuel will pool on the ground, increasing the danger of fire. Natural gas is non-toxic and will not contaminate groundwater if spilled. Advanced CNG engines guarantee considerable advantages over conventional gasoline and diesel engines. CNG is a largely available form of fossil energy. The exploitation of full potential of CNG as an alternative fuel is means of reducing exhaust gas emissions. However, the research of applying natural gas as an alternative fuel in engines will be an important activity, because the liquid fossil fuels will be finished and will become scarce and most costly. CNG has some advantages compared to gasoline and diesel fuel from an environmental perspective. It is a cleaner fuel than either gasoline or diesel fuel as far as emissions are concerned. CNG is considered to be an environmentally clean to those fuels. Another that, the advantages of CNG as a fuel are octane number is very good for SI engines. Octane number is a fast flame speed, so the CNG engine can be operated in high compression ratio.

Trails has been conducted in the SI bi-fuel engine fuel as CNG and gasoline under different testing conditions and the results were compared to achieve the lower emissions.

II. Literature survey

The use of gas (as opposed to gasoline) as a transport fuel has a history almost as long as the motor car itself. Early engines were known to make use of coal gas or town gas as a fuel source. While the gas itself proved to be a good performer, probably the key reason why it didn't take off at the time was the simple matter of on-board storage. Liquid fuels such as petrol and diesel (and alcohol) proved to be more 'user friendly' thus they won the day and liquid fuels became the 'status quo'. More than that, they have become the lifeblood of the world economy, with crude oil taking the role of the key currency.

However, times have changed now and one wonders, if we knew back then what about producing, transporting and storing gases now, how much different the world would be - not just in terms of transport but even politically, economically, and militarily. Fortunately it was learned a lot about gases in the meantime, with natural gas first making headway on our roads in the 1930s and 40s. The depression and the II World War saw the birth of creative ideas for the storage and transport of natural gas.

The benefits of natural gas vehicles are well known already, particularly here in India, but they deserve a quick mention - reduced air pollutants, reduced greenhouse emissions, increased safety over other fuels, lower cost, improved energy independence due to the wider distribution of natural gas, and now, the onset of 'renewable natural gas' (more on that soon). According to Brett Jarman[1] CNG does have some limitations, the lower fuel density means more frequent refueling, and the high pressures involved can prove problematic if a system is tampered with. The natural gas vehicle landscape is changing dramatically though, with fuel sources, storage and transportation all undergoing massive change. While a lot of these technologies have been around for some time, many of these have become 'viable' with the onset of peak oil and dramatic price fluctuations in oil prices.

One technical consideration with these projects is that the jury is still out on the effect of hydrogen on high pressure cylinders, piping and vehicle engines. In most jurisdictions blends of relatively low percentages of hydrogen are permitted before a fuel is considered not to be natural gas. According to Brett Jarman[1], these limits were originally set as an arbitrary limit, primarily because of the possibility of hydrogen causing embrittlement in components. A theoretical 'safe' limit is yet to be determined and work is underway to define and amend this if require. The future for HCNG does however look bright and will help carve an easier path for hydrogen vehicles if they are to eventuate.

Improvement the new design of the CNG engine injector nozzle holes geometries of the port injection CNG engine can be achieved through increased understanding of the fuel spray process. The simulations run by Cosmos FloWork, a computation fluid dynamic (CFD) software. As per Semin [2] the simulation is focused in the 1.78mm, 3.55mm, 5.33mm and 7.1mm intake valve lift. The types of injector nozzles that used are multi holes nozzle such as 2 holes, 3 holes, 4 holes and 5 holes. The detail of the simulation methodology is start from collecting data of the engine until analyze the gas fuel spray phenomenon in combustion chamber. The results are shown that the natural gas fuel flow spray for the original injector nozzle flow is in good condition, but the gas fuel spray is not excellently because the spray is focuses in left and right side of combustion chamber. The new injector nozzle multi holes fuel spray is more excellent than the original, where in the new injector the fuel has spray in spread in the combustion chamber. Compressed natural gas is the Gas Fuel Spray Simulation of Port Injection Compressed Natural Gas Engine Using Injector Nozzle Multi Holes 189 most favourite for fossil fuel substitution.

CNG is a gaseous form of natural gas was compressed, it have been recognized as one of the promising alternative fuel due to its substantial benefits compared to gasoline and diesel fuel. These include lower fuel cost, cleaner exhaust gas emissions, higher octane number and most certainly. Therefore, the numbers of engine vehicles powered by CNG engines were growing rapidly. Natural gas is safer than gasoline in many respects.

CNG is a largely available form of fossil energy. The exploitation of full potential of CNG as an alternative fuel is means of reducing exhaust gas emissions. According to Semin [2] the research of applying natural gas as an alternative fuel in engines will be an important activity, because the liquid fossil fuels will be finished and will become scarce and most costly. CNG has some advantages compared to gasoline and diesel fuel from an environmental perspective. It is a cleaner fuel than either gasoline or diesel fuel as far as emissions are concerned. CNG is considered to be an environmentally clean to those fuels. Another that, the advantages of CNG as a fuel are octane number is very good for SI engines. Octane number is a fast flame speed, so the CNG engine can be operated in high compression ratio.

Improvement the new design of the CNG engine injector nozzle holes geometries of the port injection CNG engine can be achieved through increased understanding of the fuel spray process and this effect on engine performance and emissions. In the latter, a model can be developed based on computational simulation and experimental then for the further will be tested by comparing both them. In any research, the physically model was developed after the computational modeling to reduce the economically cost, materials and time. To improve of CNG engine nozzle hole geometry and understand of the processes in the air-fuel mixing and combustion is a challenge because the compression-ignition combustion process is unsteady, heterogeneous, turbulent and three dimensional, very complex.

The gaseous fuel injector nozzle holes geometry can be variation with any holes geometry, to improve the perfect of mixing process of CNG fuel and air in combustion chamber, for example with arranging of nozzle hole geometry, nozzle spray pressure, modification of piston head, arranging of piston top clearance, letting the air intake in the form of turbulent and changing the CNG fuel angle of spray. The CNG fuel spraying injector nozzle is the level of earning variation so that can be done by research experiment and computational simulation. Based on research results with the Trans-Valve-Injection (TVI) system, a high-speed gas jet is pulsed from the intake port through the open intake valve into the combustion chamber, where it causes effects of turbulence and charge stratification particularly at engine part load operations. The system is able to diminish the cyclic variations and to expand the limit of lean operation of the engine. The flexibility of gas pulse timing offers the potential advantage of lower emissions and fuel consumption.

With three types of multi point injection (MPI) injectors available on the market, was compared for stationary and transient engine operation. There are several advantages of MPI, e.g., better possibility to equalize the air-fuel ratio of the cylinders, optimization of the gas injection timing and of the gas pressure for different operating conditions. According to that the sequential or MPI system has advantages for the more efficiency. According to Semin [2] this research will develop the sequential port injection CNG engine using new injector nozzle multi holes geometries. The objectives on the gas fuel spray simulation of sequential port injection CNG engine using injector nozzle multi holes is to simulate the injected gas fuel spray effect in combustion chamber of sequential port injection dedicated CNG engine based on variation intake valve lift.

The increasing cost of petroleum-based fuels and the stringent regulations regarding limits for exhaust emissions in recent years have increased interest in alternative fuels for automotive engines. The converted engine uses the intrinsic fuel system (i.e. carburetor or port injection) to deliver fuel to the cylinder. Based on How Heoy Geok [3] these result in some drawbacks, mainly reduced power and limited upper speed, which are due to lower charge inhaled energy (due to reduced volumetric efficiency) and slower flame speed respectively.

It is reported that power, volume efficiency and brake mean effective pressure (BMEP) were reduced significantly when converting port injection engine from gasoline to natural gas. One of the methods to mitigate the problems is by directly injecting natural gas into the combustion chamber. Direct injection (DI) system can increase the absolute heating value of the cylinder charge and enhance turbulence intensity for better mixing prior to ignition. As a result, it can improve the combustion efficiency for better torque and power, reduce pumping and heat losses and control the air fuel ratio of the engine more precisely. Besides, DI of natural gas can maintain the smoke free operation of SI engines and produce lower NOx emissions compared to the unthrottled diesel engines. However, the development of new direct injection engine is costly and technically difficult to achieve within a short period of time. This is due to the needs for development of new cylinder head to acclimate with direct fuel injector and also involves tedious calibration of the engine control system.

Sequential port injection (or multi-point injection) of natural gas can offer an immediate solution for the drawbacks of CNG converted engine. NG is injected by individual injector at each cylinder intake manifold just before the opening of intake valve. Better control of mixture formation and response to changing speed can be achieved. Thus, it provides the opportunity to reduce the negative effects on the performance compared to carburetor-type or single injector manifold injection. The results obtained from experimental investigation of the sequential port injection natural gas engine with respect to performance and exhaust emissions were compared.

According to Munde Gopal, G [4], the compressed natural gas vehicles exhibit significant potential for the reduction of gas emissions and particulates. There are many problems for compressed natural gas applications such as onboard storage due to low energy volume ratio, knock at high loads and high emission of methane and carbon monoxide at light loads. However these can be overcome by the proper design, fuel management and exhaust treatment techniques.

Darade.P.M. [5] says that the greatest opportunity for improving the efficiency and performance of spark ignition engines are by way of higher compression ratio, variable valve timing and low friction. The compression ratio also affects many performance parameters and emissions. Variable compression ratio is recognized as a method for improving fuel economy in spark ignition engines.

One of the major benefits of using natural gas as an engine fuel is that exhaust gas emissions can be reduced compared to the levels achievable with either gasoline or diesel fuel. One of the methods of achieving reduced emissions from spark ignited IC engines is to use a three way catalytic converter with careful control of air-fuel ratio to the stoichiometric value. An alternative, but particularly promising, operating strategy for reducing emissions of nitrogen oxides, carbon monoxide and unburned hydrocarbons is to run the engine at very lean air-fuel ratios, using so called 'lean-burn' strategy.

Implementation of this strategy eliminates the costly catalytic converter and the attendant control problems associated with the need to keep the precise control of air-fuel ratio. Using a lean burn strategy with a carefully optimized spark ignited natural gas engine may result in both light duty and heavy duty engines meeting current and proposed emissions regulations without the use of the expensive catalytic converter. Another benefit of lean operation is increased thermal efficiency in due to an increase in the ratio of specific heats for lean mixtures.

Natural gas is particularly benefit for this particular strategy since it has wider flammability limits than does gasoline, enabling an engine to operate at leaner air-fuel ratios with a consequent reduction in nitrogen oxide emissions. Operation with natural gas mixtures at a fixed part- load condition also leads to increased thermal efficiency due to a reduction in throttling losses. Evans R.L.[6] says that the objective of this work was to obtain a detailed comparison of engine performance and exhaust emissions from natural gas and gasoline fuelled spark engines over a wide range of engine speeds, loads and air-fuel ratios under carefully controlled steady state operating conditions.

Many comparative studies of natural gas and gasoline as engine fuels have been published, but these have nearly all utilized natural gas conversions of standard gasoline automobile engines. Such conversions normally use simple gas carburetion systems which have very air-fuel ratio control compared to modern fuel injected gasoline engines. In many cases the result published for natural gas operation have shown lower exhaust emissions for the gasoline fuelled vehicles, primarily because of the better air-fuel ratio control. This study was designed, therefore, to ensure that accurate measurements of performance and exhaust emissions were obtained under carefully controlled Air-fuel ratio conditions for both fuels.

Engines are basically air pumps. For more power, an engine must burn more fuel; hence more air must be pumped into the cylinders. The amount of air available to the engine depends on the resistance to the flow through the engine intake system, cylinder and exhaust system. The ability of the engine to pump the air is called volumetric efficiency. If this is reduced the maximum power output will be reduced in the similar manner. Liquid fuel when atomized generally consumes very small space in the intake system, thus do not affect the volumetric efficiency significantly. While gaseous fuels require 4 to 15 percent of intake passage volume. Space occupied by the fuel reduces the amount of air entering the engine; hence the power output of the engine is reduced. According to Bhandari Kirti [7] theoretically, loss in power output for LPG (4%) is less than NG (9.5%).

III. Experimental setup and procedure

A 0.8 liter, multipoint fuel injection gasoline engine (Maruti 800) was converted to a CNG-gasoline bi-fuel sequential type port fuel injection and can be 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 experimental setup and the schematic diagram are shown in Fig. 1and Fig. 2 respectively. An eddy current dynamometer and Ni-DAQ data acquisition system were used to program the engine test as well as recording engine performance data. The engine was run at steady state conditions with wide open throttle at constant speed ranging from 1500 to 5000 rpm with 500 rpm increment for both gasoline and CNG.

CNG is stored at 200 bar pressure in a tank and its pressure was reduced to 1.5 bar by a pressure regulator and a reducer as it is injected into the intake manifold. A check valve was installed on the fuel system to prevent the backflow of gas. The injection of CNG was controlled by the TAMMONA CNG control software for the engine tuning calibration at different speeds. Gasoline consumption was measured using a volume-scaled pipette and time recording. The mass flow rate of CNG was measured with digital weighing balance. A pressure sensor (Kistler type 6125B) was installed to one of engine cylinders and pressure data was sent to data acquisition system. Exhaust emissions for both fuels were measured by AVL 5 gas analyzer.

Fig. 1 3 -Cylinder MPFI water cooled computerized SI engine

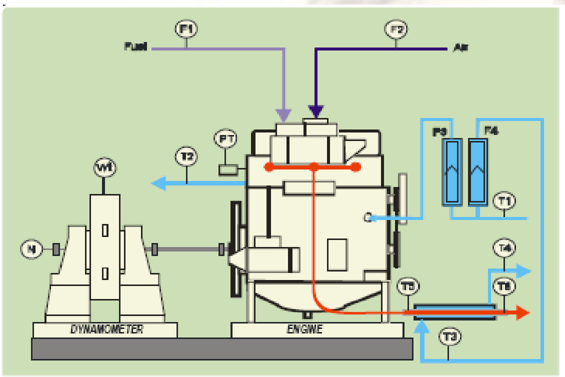


Fig. 2 Schematic of Experimental set up

T1 – Inlet water temperature to the Engine
T2 – Outlet water temperature from engine
T3 – Inlet water temperature to exhaust gas calorimeter
T4 – Outlet water temperature at exhaust gas calorimeter
T5 – Temperature of water at Engine outlet / at Calorimeter inlet
T6 – Temperature of water at Calorimeter outlet

Table 1 Engine and Dynamometer Specification

Engine Make	Maruti
Model	Maruti 800, 796 CC
Type	3 Cylinder, 4 stroke
Fuel	Petrol(MPFI)
Cooling	Water Cooled
Power	27.6 kW @ 5000 rpm
Bore (d)	66.5 mm
Stroke	72 mm
Dynamometer type	Eddy Current
Compression ratio	9.2:1
Orifice Diameter (d_o)	35 mm
Dynamometer Arm Length	210 mm

3.1 Engine test

Tests were conducted under 100% wide open throttle (WOT) and two part load (50% and 25% of full load) conditions. The four stroke engine also 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 be recorded if required. Although this is a low compression ratio engine for natural gas, with its high octane rating, a direct comparison of the two fuels when used in the same engine build was focus of this investigation.

IV. Observations and results

The engine is run at wide open throttle and constant speed ranging from 1500 to 5000 rpm with around 500 rpm increment. However, the volumetric efficiency is reduced by 4-10% with CNG operation. Due to this, the brake torque, brake power and brake mean effective pressure of the engine are reduced by 8-16%. In terms of exhaust emissions, the results will be that HC, CO and CO_2 will be significantly reduced by 40-66%, 55-87% and 28-30 % respectively compared to gasoline.

Experiments were conducted for WOT, 25% and 50% of throttle opening. Engine speed, temperature at various locations and the gas analyzer readings for CO, CO_2, NOx and HC were recorded for gasoline as well as CNG fuel.

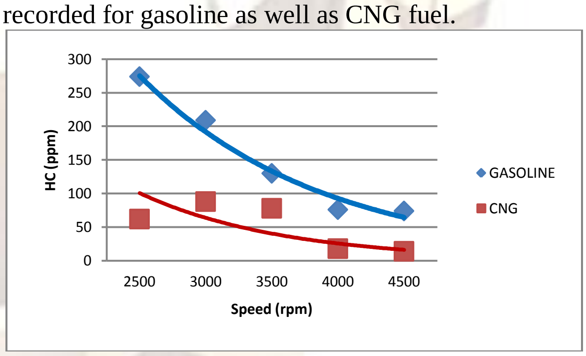


Fig. 3 Hydrocarbon versus engine speed

Fig. 3 compares the HC emission for CNG and gasoline. For fuels CNG and gasoline at 2500 rpm the exhaust gas contains around 50 ppm and 250 – 300 ppm of HC respectively.

Carbon content of CNG is 8 times lesser than the gasoline, which reduces carbon based emissions. Also in the gaseous fuel complete combustion takes place, which reduces HC emissions. More homogeneous mixture is formed in gaseous fuel compared to liquid fuels. Further reduction of HC can be done using higher compression ratio dedicated CNG engine.

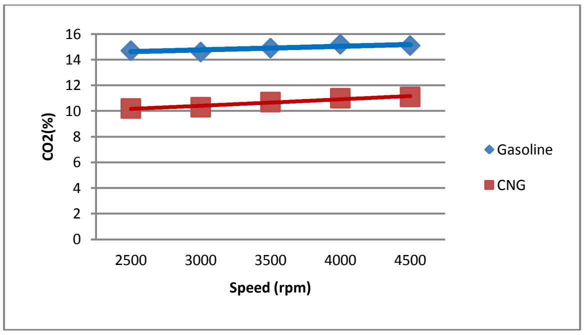


Fig.4 Carbon Dioxide versus engine speed

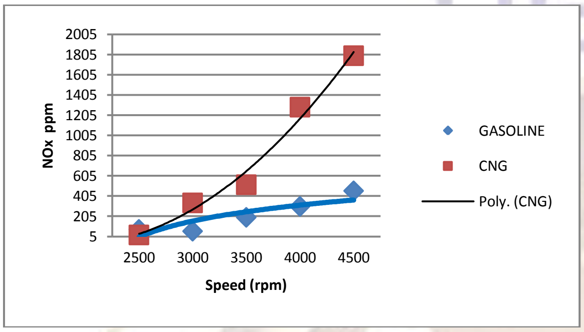


Fig. 5 Nitrogen oxide versus engine speed

Fig.4 shows the graphical comparison of CO_2 content in the exhaust gas. For fuel as CNG against gasoline, CO_2 emissions were lower at different speeds of engine.

Figure 5 shows the graphical comparison of NOx content in the exhaust gas. For fuels CNG and gasoline at 4500 rpm the exhaust gas contains around 1800 ppm and 400 ppm of NO_x respectively. Nitric oxide (NO) and nitrogen dioxide (NO_2) are usually grouped together as NO_x emissions. NO is the predominant oxide of nitrogen produced inside the engine cylinder. Principal source of NO_x is oxidation of atmospheric (molecular) nitrogen and high combustion temperature. It is observed that in CNG NOx emissions are more due to increase in temperature during combustion. NOx can be reduced by retarding the spark timing or forming lean burn combustion.

EGR or steam injections are some of the techniques used for NOx reduction. It is observed that at higher speed and higher load NOx formation is more. At higher speed & higher load NOx formation is less for gasoline as the engine is dedicated gasoline engine. EURO V norms are more stringent for NOx emissions as it forms nitric acid when comes in contact with the atmospheric water vapour.

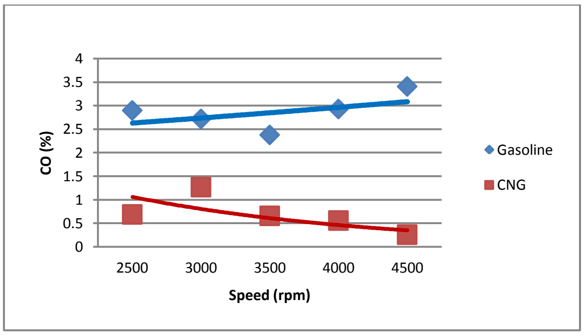


Fig. 6 Carbon monoxide versus engine speed

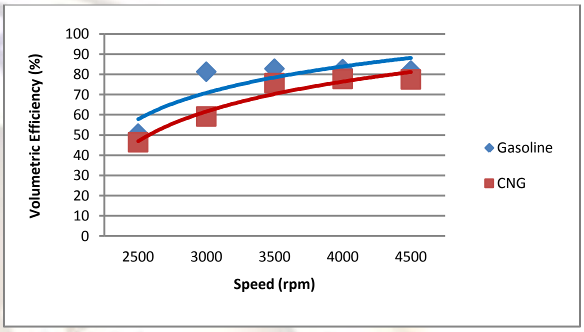


Fig. 7 Volumetric efficiency versus engine speed

Carbon monoxide content was lesser while the engine using CNG fuel as against gasoline, at various speeds. This comparison is shown in Fig.6 When Gasoline was used as fuel there were some possibilities of improper mixing. Consequence of this lead to CO emissions.

Variation of volumetric efficiency of the engine at different speeds is being shown in Fig. 7. At the speed of 3000 rpm it is 80% for gasoline and 58% for CNG.

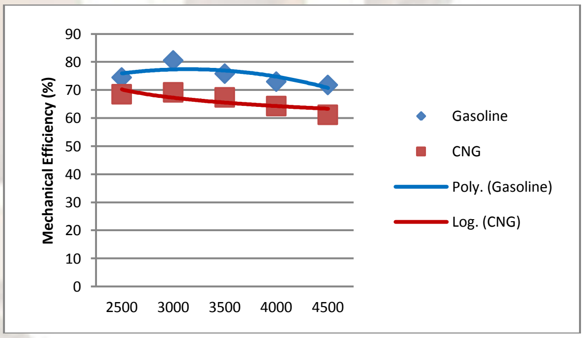
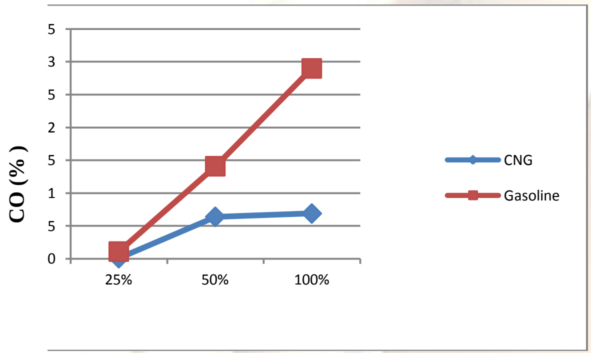


Fig. 8 Mechanical efficiency versus engine speed

Variation of mechanical efficiency of the engine at different speeds is being shown in Fig. 8. At the speed of 3000 rpm it is 70% for CNG and 80% for gasoline.

Table 2 Comparison of emission of exhaust gases at different throttle opening

Throttle Open	Exhaust gases	Gasoline	CNG
25%	CO (%)	0.11	0.02
	CO_2(%)	14.3	9.3
	HC(ppm)	23	14
	NOx(ppm)	21	29
50%	CO (%)	1.41	0.64
	CO_2(%)	14.6	10.4
	HC(ppm)	56	33
	NOx(ppm)	32	139
100% WOT	CO (%)	2.9	0.69
	CO_2 (%)	14.9	10.6
	HC(ppm)	274	62
	NOx(ppm)	58	338



Engine Throttle Opening level
Fig. 9 Carbon monoxide versus Engine throttle opening

In the Fig. 9 it is shown that there was reduction in CO emission with CNG as fuel as against gasoline at different throttle opening. When Gasoline was used as fuel there were some possibilities of improper mixing. Consequence of this lead to CO emissions
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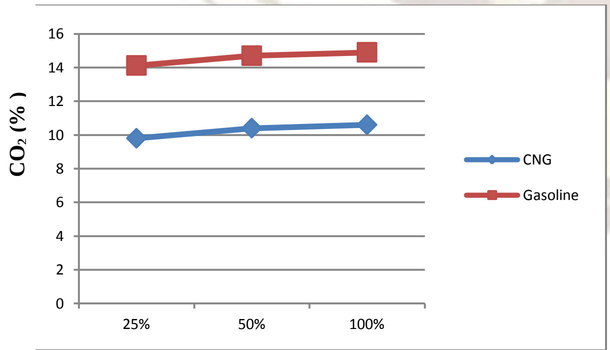
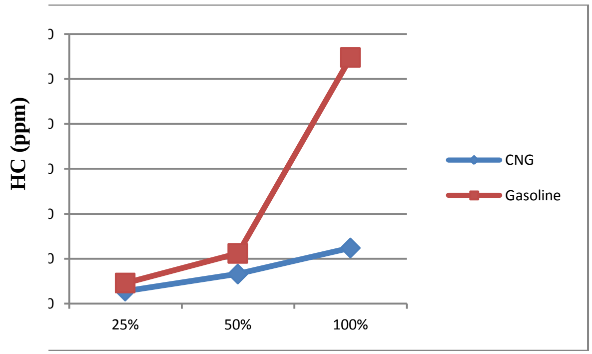


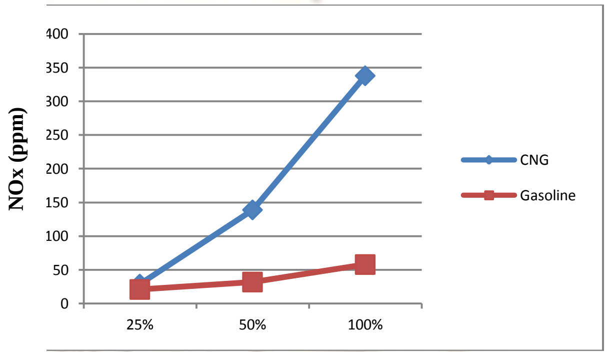
Engine Throttle Opening level

Fig. 10 Carbon Dioxide versus Engine throttle Opening



Engine Throttle Opening level

Fig. 11 Hydrocarbon versus Engine throttle opening



Engine Throttle Opening level
g. 12 Nitrogen oxides versus Engine throttle Opening

In Fig. 10 it is shown that the overall Carbon dioxide content in the exhaust gas was lower for the engine with CNG as fuel as against gasoline, at various throttling.

Hydro carbon emission was reduced in exhaust gas with CNG as fuel as against gasoline at various throttle opening. Which is shown in the Fig. 11

Nitrogen oxides emission was found increased in exhaust gas with CNG as fuel as against gasoline at various throttle opening. Which is shown in the Fig. 12

V. Conclusions and scope for further work

This study has demonstrated that sequential type CNG conversion kit gasoline engine has a potential for improved fuel economy and higher fuel conversion efficiency with significantly lower exhaust emissions. The following remarks can be drawn as the conclusions for this study:

1. Reduction in CO, CO_2 and HC emissions at 25% throttle opening with CNG as fuel as against Gasoline were 81.81%, 34.96%, 39.13% respectively while NOx increasing 27.58%

2. Similar results at 50% of throttle opening were 54.6%, 29.25% and 41.07% , while NOx increase was 76.97%
3. At 100% of throttle opening similar results showed 76.2%, 28.85% and 77.37%, while NOx increase was 82.84%
4. Under the same engine operations and configurations, sequential port injection CNG operations shows 20% reduction in Mechanical efficiency was observed at 25% throttle.
5. Air fuel ratio is reduced by 43%, 38.35% and 18% at 25%, 50% and 100% throttle respectively. CNG produces less 8-16% of torque compared to gasoline.
6. Considerable improvement in the emission characteristics of the engine using CNG fuel as against gasoline, at all remaining conditions.

VI. Scope for further work

Further work can be extended to evaluate the performance of engine using CNG blended with Hydrogen and emission characteristics studied.

References

[1] Brett Jarman, "Beyond CNG – Natural gas vehicles in the Years Ahead", *The Automotive Research Association of India*, 2009

[2] Semin, Abdul Rahim Ismail, and Rosli Abu Bakar, " Gas Fuel Spray Simulation of Port Injection Compressd Natural Gas Engine Using Injector Nozzle Multi Holes", *European Journal of Scientific Research*, pp.188-193, 2009.

[3] How Heoy Geok, Taib Iskandar Mohamad, Shahrir Abdullah, Yusoff Ali, Azhari Shamsudeen, and Elvis Adril "Experimental Investigation of Performance and Emission of a Sequential Port Injection Natural Gas Engine", *European Journal of Scientific Research*, pp.204-214, 2009.

[4] Munde Gopal, G. and Dr. Dalu Rajendra, S. "Compressed Natural Gas as an Alternative for Spark ignition Engine: A Review" , *International Journal of Engineering and Innovative Technology(IJEIT)*, Volume 2, Issue 6, December 2012.

[5] Darade, P.M. and Dalu, R.S. "Investigation of Performance and emissions of CNG fuelled VCR engine", *International Journal of Emerging Technology and Advanced Engineering(IJETAE)*, Volume 3, Issue 1, January 2013

[6] Evans, R. L. and Blaszczyk, J. "A comparative study of the performance and exhaust emissions of a spark ignition engine fuelled by natural gas and gasoline", *Proceedings of the Institute of Mechanical Engineers, Part:D Journal of Automobile Engineering*, Jan 1, 1997, pp. 39-47

[7] Bhandari Kirti, Bansal Akhil, Shukla Anuradha, and Khare Mukesh "Performance and emissions of natural gas fueled internal combustion engine: A review", *Journal of Scientific and Industrial Research*, Vol 64, May 2005, pp. 333-338