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Compressed Natural Gas as an Alternative Fuel for Spark Ignition Engine: A Review

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Abstract* — The research on alternative fuels for internal combustion engine has become essential due to depletion of petroleum products and its major contribution for pollutants, where Natural gas is one of the most promising fuel alternatives for the future. Independent of vehicle category, natural gas will help to bring down harmful emissions. Compressed natural gas (CNG) has long been used in stationary engine , but the application of CNG as a transport engine fuel has been considerably advanced over the last decade by the development of lightweight high pressure storage cylinder. There are various methods which use the compressed natural gas in IC engine with little modification. It is revealed that the performance characteristics are lower while the emission characteristics of CO, CO2 HC are better for Natural gas compared to petrol or diesel and improvement is seen with the increasing of density. In this paper, a comprehensive review of the CNG engines research and development fuelled using CNG are highlighted to keep the output power, torque and emissions of natural gas engines comparable to their gasoline or diesel counterparts. The high activities for future CNG engines research and development to meet future CNG engines is recorded in the paper.

Index Terms— **Alternative Fuel, CNG, Dual Fuel and Bi Fuel Engine, Performance, Low Emission.**

NOMENCLTURE

Abbreviation	Meaning
CI	Compression Ignition
SI	Spark Ignition
CNG	Compressed natural gas
HCNG	Hydrogen blended compressed natural gas
BMEP	Brake mean effective pressure
BSFC	Brake specific fuel consumption
CR	Compression ratio
WOT	Wide open throttle
MBT	Maximum brake torque
EGT	Exhaust gas temperature
EFI	Electronic fuel injection
TDC	Top dead centre
BDC	Bottom dead centre

I. INTRODUCTION

Impending possible energy crisis in future, rising costs and toxic emissions associated with conventional petroleum fuels have caused researchers to search out and investigate the possibility of utilization of alternate clean and non-polluting gaseous fuels for internal combustion engines. With rising amount of cars and decreasing of oil resources, it seems that the use of alternative fuels is inevitable in the future. To meet the required demand the alternative fuels used in gasoline and diesel engines are becoming the subjects of interest today. When evaluating different alternative fuels one has to take into account many aspects Adequacy of fuel supply, Process efficiency, Ease of transport and safety of storage, Modifications needed in the distribution/refuelling network in the vehicle, Fuel compatibility with vehicle engine (power, emissions, ease of use, and durability of engine).[3] Alternative fuels used in gasoline and diesel engines are becoming the subjects of interest today. Most of the concerns are driven by two factors: various new laws pertaining to clean air and energy independence from petroleum based fuel. CNG (compressed natural gas), a gaseous form of natural gas, clearly has some substantial benefits compared to gasoline and diesel. These include lower fuel costs, higher octane and, most certainly, cleaner exhaust emissions. As a result, CNG as a fuel is clean, economical and has been in use worldwide to power vehicles. CNG is colourless, odourless, non-toxic, lighter than air and inflammable. There are over 1,500,000 vehicles in the world produced by Honda, Ford, Toyota, Volvo, Mercedes Benz, Optare, Iveco, Cummins and Scania running on CNG . Many investigations were carried out in order to use of CNG as an alternative fuel in an engine could be divided into three main types according to their fuel usage and they are: Dual Fuel, Bi-Fuel, and Dedicated/Mono Fuel.

A. Dual Fuel

This is a development from conventional diesel engine. In this type of engine, both diesel and natural gas were introduced into the engine cylinders during compression. As natural gas will not ignite under compression alone, the diesel is required to act ignite the gas/air mixture. When natural gas refuelling points are not available, the engine can revert to conventional operation.

B. Bi-Fuel

This type of engine development is based on the conventional petrol engines where the fuel system has been modified to operate either petrol or gas. When natural gas refuelling is not available, normal running on petrol is possible.

C. Dedicated/Single Fuel

This is a specialized engine type, which has been designed and optimized to operate only on natural gas. This enables the

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characteristics of natural gas to be fully exploited without the need to compromise in design to enable other fuel usage.

II. NATURAL GAS AS AN ALTERNATIVE FUEL

Natural gas is produced from gas wells or tied in with crude oil production. Natural gas (NG) is made up primarily of methane (CH4) but frequently contains trace amounts of ethane, propane, nitrogen, helium, carbon dioxide, hydrogen sulphide, and water vapour. Methane is the principal component of natural gas. Normally more than 90% of natural gas is methane, the detail of natural gas compositions as shown in Table 1. by Shasby ,Semin [2].There are three forms of natural gas: liquefied natural gas (LNG), liquefied petroleum gas (LPG) and compressed natural gas (CNG). Both LNG and CNG are based on methane. The difference is LNG made by refrigerating natural gas to condense it into a liquid while CNG still in the gaseous form. LNG is much more dense than natural gas or CNG. That means LNG is good for large trucks that need to go a long distance before they stop for more fuel. LPG is based on propane and other similar types of hydrocarbon gases. These hydrocarbons are gases at room temperature, but turn to liquid when they are compressed. [9] Thus increase in the availability of the gaseous fuels and the demand to use them for power generation has led to manufacturing of the gas engines.

Table 1: Typical Composition of Natural Gas

Composition	Formula	Volumetric %
Methane	CH_4	94.07
Ethane	C_2H_6	4.6
Propane	C_3H_8	1.13
Iso-Butane	i-C_4H_{10}	0.21
N-Butane	n-C_4H_{10}	0.29
Iso-Pentane	i- C_5H_{12}	0.10
N-Pentane	n- C_5H_{12}	0.08
Nitrogen	N_2	1.02
Carbon .Dioxide	CO_2	0.26
Hexane	C_6+(C_6H_{14})	0.17
Oxygen	O2	0.01
Carbon Monoxide	CO	<0.01
Total	-	100

Natural Gas has been tested as an alternative fuel in a variety of engine configurations. The four main engine types include the traditional premixed charge spark ignition engine, the lean burn engine, the dual fuel/ pilot injection engine, and the direct injection engine.[2] Natural gas is stored on-board as either compressed natural gas (CNG) or liquefied natural gas (LNG) - the latter at190°C. CNG is the most common option for cars. The gas is stored in pressurized 200-270 bar cylinders, which are located within the boot space. Cars used to have a single steel cylinder; new cars contain several smaller composite cylinders. Being pressurized, it is heavier than conventional fuel tanks and increases the car total weight by around 60 kg.[8] Compressed natural gas (CNG) has been used as an alternative fuel. The advantages of CNG compared to petrol are: Unique combustion and suitable mixture formation; Due to high octane number of CNG, engine operates smoothly with high compression ratios without knocking; CNG with lean burning quality will leads to lowering exhaust emissions and fuel operating cost; CNG has a lower flame speed; Engine durability is very high. [4] The flame speed of Natural gas is lower compared to petrol (Aslam et al., 2006). CNG is almost perfect knock resistant and these characteristics do not significantly vary with the small addition of hydrogen [14]. The CNG fuel properties and characteristics are shown in Table 2.

Table 2: Typical Composition (Vol %) of Compressed Natural Gas:

Component	Symbol	Volumetric %
Methane	CH_4	94.42
Ethane	C_2H_6	2.29
Propane	C_3H_8	0.03
Butane	C_4H_{10}	0.25
Nitrogen	N_2	0.44
Carbon dioxide	CO2	0.57
Others	-	2

According to M.I, Jahirul,[4] the compressed natural gas vehicles exhibit significant potential for the reduction of gas emissions and particulates. There are any 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. Thermodynamic properties of petrol and CNG are given in the Table no.3.

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Table 3: Thermodynamic Properties Gasoline & CNG [1, 3, 4, 8]

Properties	Gasoline	CNG
Stoichiometric ratio	14.2	15.7
Octane number	96	120-130
Higher heating value (MJ/kg)	45	50.3
Lower heating value (MJ/kg)	42.2	45.9
Density @ 25° C (kg/m3) (DIN 51757)	749	2.52
Molecular weight (kg/kmol)	106.2	16
Minimum Ignition Energy(MJ)	0.33	0.26
Laminar flame speed(cm/sec)	30	37.5
Flammability limits(Vol% in air)	5.2	15.6
Adiabatic Flame Temp (K)	2227	2266

III. PRESENT STATUS ON CNG ENGINES

M.U. Aslam et al[2006] carried out the experiment on a 1.5 L, 4-cylinder Proton Magma retrofitted spark ignition car engine with dynamometer. The engine was converted to computer integrated bi-fueling system from a gasoline engine and was operated separately either with gasoline or CNG using an electronically controlled solenoid actuated valve system. The results indicate that with retrofitted CNG engine produces around 16% less BMEP and consumes 17–18% less BSFC, or consumes an average of 1.65 MJ less energy per kWh at WOT condition with CNG compared to gasoline. The engine shows an average of 2.90% higher FCE nearly at stoichiometric air–fuel ratio (lZ1) with CNG at WOT condition and this higher value decreases with the decrease of l value. On average retrofitted engine reduced CO by around 80%, CO2 by 20% and HC by 50% and increases NOx emissions by around 33% with CNG compared to gasoline. M.I. Jahirul et al [2010] have worked on Comparison engine performance and emission analysis of CNG and gasoline. The test was carried out with in a retrofitted car engine use a 1.6 L, 4- cylinder petrol engine was converted to the computer incorporated bi-fuel system which operated with either gasoline or CNG using an electronically controlled solenoid actuated valve mechanism. The engine performance and exhaust emission was measured over a range of speed variations at 50% and 80% throttle positions. . The results showed that, 19.25% and 10.86% reduction in BP and 15.96% and 14.68% reduction in BSFC at 50% and 80% throttle positions respectively while the engine was fueled with CNG compared to that with the gasoline. Other emission contents (unburnt HC, CO, O2 and CO2) were significantly lower than those of the gasoline emissions. ETSAP [2010] mentioned the advantage of using LPG and natural gas engines as a fuel on Bi-fuel mode and showing the cost effectiveness and environmental impacts and clearly mentioned the present status of LPG and CNG as the fuels and their growing demands worldwide. M.K Hassan, I.Aris, S..Mahmod, R. Sidek[2010] worked on Experimental investigations of performance and exhaust gases, concentration at various ignition and injection timing for high compression engine fuelled with compressed natural gas (CNG) engine. The engine implements central direct injection (DI) method. All injectors are positioned within a certain degrees of spark plug. It is called as CNGDI engine. The results showed that, Low CO concentration occurs at late injection timing and the lowest emission is 0.011% when we applied 300 bTDC of ignition at 3600 CA injection timing. The most influential factor for CO development is ignition timing. Complete combustion occurs at (3000 EOI, 250-280 bTDC) as illustrated in the CO2 and O2 contour. R. Chandra, V.K. Vijay , P.M.V. Subbarao , T.K. Khura [2011] carried out the Performance evaluation of a constant speed IC engine on CNG, methane enriched biogas and biogas .On a 5.9 kW stationary diesel engine which was converted into spark ignition mode and run on compressed natural gas (CNG), methane enriched biogas (Bio- CNG) and biogas produced from bio methanation of jatropha and pongamia oil seed cakes . The performance of the engine with 12.65 compression ratio was evaluated at 300, 350and 400 ignition advance of TDC. They observed that power losses due to conversion of diesel engine into spark ignition engine .The engine test results obtained in terms of brake power output, specific gas consumption and thermal efficiency on methane enriched biogas containing 95% methane has showed that the engine performance is almost similar to that of compressed natural gas. Thus, the gaseous fuel methane enriched biogas is as good as natural gas. Mardani Ali Sera et al Had investigate the effects of density on the performance of a CNG fuelled engine either in dual-fuel, bi-fuel or dedicated forms is lower performance compare to that of gasoline. One significant factor that reduces the CNG engine performance is its low volumetric efficiency due to low density of a CNG fuel. In this research the cooling system and heat exchanger device were installed to 16 L EFI engine to vary the density of CNG fuel. The results showed that the fuel density plays an important effect on the performance of CNG engine and at the same time maintaining the lower exhaust emissions. E. Ramjee and K. Vijaya Kumar Reddy [2011] worked on experimental investigations on a single cylinder 4-stroke air cooled type Bajaj-Kawasaki petrol engine to compute performance and exhaust emissions of the test engine. All tests have been carried out under steady state conditions for both petrol and CNG fuels and the results have been compared. They found that for all range of speeds, the volumetric efficiency is reduced and various between 10-14%;Except thermal efficiency the other performance parameters viz BMEP, Torque, Power and BSFC are decreased for CNG fuelled engine compared to petrol fuelled engine; Except NOx the other emission characteristics such as CO, CO2, and HC are decreased. Pravin T. Nitnaware, Jiwak G. Suryawanshi [2011] the main purpose of the researches to obtained design and improve low flame propagation and poor combustion stability of Natural Gas fuelled engine and investigate the combustion behaviours of sequential gas injection in multi-cylinder SI engine operation. In this research, experiments were carried out to obtained the results from running a 3-cylinder spark ignition engine with gasoline and compressed natural gas (CNG).They found that on average CNG yielded 19 % less BSFC, Compared to gasoline. However, the volumetric efficiency was reduced by 5-17 % with CNG operation. Due to this, the brake torque, brake power and brake mean effective pressure of the engine were reduced by 8-16%. In terms of exhaust emissions, WOT results showed that HC, CO and CO2 were significantly reduced compared to gasoline. Reji Mathai , R.K. Malhotra , K.A. Subramanian , L.M. Das [2012] have worked on the effect of compressed natural gas (CNG) and 18% hydrogen blended compressed natural gas (HCNG) on a retrofitted gasoline genset engine's performance, emissions, deposits and lubricants under long duration testing. The test was carried out with a Honda twin-cylinder water cooled gasoline engine .The results showed that, HCNG fuelled engine decreased BSFC, CO and HC emissions with penalty of NOx emission. HCNG operation significantly reduced the kinematic viscosity and TBN and increased wear metal of Fe and Cu in lubricant. After the 60 h of tests, gaseous fuels did not show any abnormal wear or deposits on engine components. Higher deposits of Iron on the spark plug and Iron oxide on the cylinder liner are observed for HCNG fuel. To achieve the optimum operation of CNG engine as Operated in high volumetric Efficiency, High Flame Speed, High Compression Ratio, Suitable Air fuel Ratio, Low Emission, Fuel Storage System many researchers and institutions have contributed in improving the CNG engine performance. In area of increasing volumetric efficiency, Fanhua Ma et al [10] developed an electronically controlled natural gasfuelled engine with a turbocharged spark-ignition natural gas engine controlled by an electronic control. The experimental data was taken at hydrogen fractions of 0%, 30% and 55% by volume and was conducted under different excess air ratio (l) at MBT operating conditions system. It is found that under various results the addition of hydrogen can significantly reduce CO, CH4 emissions and the NOx emission remain at an acceptable level when ignition timing is optimized. Using the same excess air ratio, as more hydrogen is added the power, exhaust temperatures and max cylinder pressure decrease slowly until the mixture's lower heating value remains unchanged with the hydrogen enrichment, then they rise gradually.

IV. FACTOR AFFECTING THE SUITABILITY OF AN CNG ALTERNATIVE FUEL

Most of the engines are modified from the diesel engines to run on gas by introducing the gas governing, ignition, carburetion also some changes in design by changing the compression ratio, valve timing, and changes in combustion chamber. Before any alternative fuels could be used as an alternative to petrol or diesel, it has to fulfil some criteria. Stratton, Rosli Abu Bakar [16] has listed some suitability factors that would support alternative fuel to become a choice over petroleum fuels these factors are as follows;

- Fuel Reserves
- Refuelling infrastructure
- Component availability
- Emission potential
- Safety
- Financial requirement

From the literature survey it is observed that following several factors affecting the engine run on NG for low engine power and torque are

- Loses in volumetric efficiency
- Low flame speed
- Low compression ratio (CR)
- Absence of fuel evaporation
- Change in stoichiometric air/fuel ratio

V. CONCLUSION

Based on the reviewed paper for the performance and emissions of compressed natural gas , it is concluded that the compressed natural gas represents a good alternative fuel for SI engine and therefore must be taken into consideration in the future for transport purpose. Thus a number of conclusions are drawn from the studies of various experimental results, These are follows;

- ➢ The engine thermal efficiency and exhaust gas temperature produced by the CNG burning is always higher as compared with that of the petrol/diesel
- ➢ CNG produces less 8-16% of brake torque, brake power and BMEP compared to gasoline fuel due to reduced volumetric efficiency and lower flame speed of CNG
- ➢ On average the reduction of CO, CO2 and HC emission are 20-98%, 8-20% and 40-87% respectively by CNG.
- ➢ Higher NOx emission is the main emission concern for CNG as automotive fuel that can be reduced by increasing fuel density and blending small quantities of H_2.

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