International Journal of Advance Research in Science and Engineering
Vol. No.5, Issue No. 04, April 2016
www.ijarse.com
IJARSE
ISSN 2319 - 8354

PERFORMANCE CHARACTERISTICS OF COMPRESSED NATURAL GAS AS AN ALTERNATIVE FUEL FOR INTERNAL COMBUSTION ENGINE: A REVIEW

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ABSTRACT

The development of alternative fuels such as natural gases has become very essential because of the continuously reduction in the petroleum reserves and also their involvement as pollutants. Nevertheless, today's market share of compressed natural gas (CNG) vehicles is small but rapidly increasingCNG is now emerging as an alternative energy source in the automobile sector and gaining the interest in research work nowadays. In this study the comprehensive review of various operating parameter and concerns have been prepared for better understanding of operating condition for natural gas fueled internal combustion engine. Thehigh activities for future CNG engines research and development for future CNG engines is given in the paper.

Keywords: Compressed Natural Gas, fuel characteristics, Gasoline engine.

I. INTRODUCTION

Air pollution is becoming a serious global as well as urban problem with the increasing population and subsequent demand. This resulted in an increase interest in using NG as a fuel for Internal Combustion (IC) engine.

Natural gas is produced from gas wells or tied in from crude oil production. There are three forms of natural gas: liquefied natural gas (LNG), compressed natural gas (CNG) and Liquified petroleum gas (LPG). Both LNG and CNG are based on methane. The difference is LNG is made by refrigerating natural gas to condense it into a liquid while CNG still in the gaseous form. LNG is much denser than natural gas or CNG. Natural gas (NG) is made up primarily of methane (CH_4) but frequently contains trace amounts of ethane, propane, nitrogen, helium, carbon dioxide, hydrogen sulphide, and water vapour. Methane is the main component of natural gas. Normally more than 90% of natural gas is methane [1-2].

Table 1.Natural Gas Composition [3]

Composition	Formula	Volume Fraction
Methane	CH4	92.07
Ethane	C2H6	4.66
Propane	C3H8	1.13
Iso-butane	i-C4H10	0.21
N-butane	n-C4H10	0.29
Iso-pentane	i-C5H12	0.10
N-pentane	n-C5H12	0.08
Nitrogen	N2	1.02
Carbon-dioxide	CO2	0.26
Hexane	C6+(C6H14)	0.17
Oxygen	O2	0.01
Carbon-monoxide	CO	< 0.01
Total	-	100

Most researches have focused on the use of NG as an alternative fuel, because of its wide availability, clean burning and low cost compared to other gaseous fuels.CNG consists of hydrocarbons in gaseous form, approximately 80-90 % of methane along with some of the percentage of ethane, propane, nitrogen. The main source of CNG fuel are mainly underground reserves, it can be made from agricultural waste, human waste and garbage.

There are certain advantages of Compressed natural gas is that it is non-toxic ,burn cleanly ,cheaper in cost, and has lower greenhouse gasemissions. According to [4], operating costs are some of the reasons, where natural gas powered vehicles theoretically have a significant advantage over petroleum-powered vehicles; the reason for this argument is the lower cost per energy unit of natural gas as compared to petroleum. According to Ganesan[5] some benefits of compressed natural gas as a fuel are octane number is very good for SI engine fuel, octane number is a flame speed, so engines can be operate with a high compression ratio, less engine emissions, low aldehydes than methanol and fuel is fairly abundant worldwide.

In spite of the advantages of natural gas, it has also some limitations such as low burning velocity and poor lean burn capability. According to Ganesan [5] the limitation of CNG as an engine fuel are low energy density resulting in low engine performance, low volumetric efficiency because it is a gaseous fuel. These problems lead to engines having high cyclic variation, longer combustion duration and lower power output. The difficulties with CNG arise from vehicle range, storage of fuel, infrastructure costs, and ensuring sufficient supply. According to Poulton[4]that a natural gas-powered, single-fuel vehicle should be capable of same power, similar or higher efficiency and mostly lower emissions than the same petrol-fuelled vehicle. Such a vehicle would have a shorter driving range unless the fuel tanks are made very large, which will result increase in weight, space, performance and cost. The importance of range asa vehicle characteristic is illustrated in [6]. In this case[6], the additional weight of batteries or storagecylinders need considerable extra chassis weight,requiring more fuel and storage cylinders orbatteries. Accordant to semin [7]There are many problems for CNG applications suchas onboard storage due to less energy volume ratio,knock at high loads and more emission of methane andcarbon monoxide at low loads. However, these can beovercome by the proper design, fuel management and exhaust treatment techniques.

II. CNG FUEL CHARACTERISTICS

NG defuses in air fuel mixture at lower inlet temperature than is possible with either gasoline or diesel .this lead easier starting more reliable idling,smooth acceleration and more complete and efficient burning with less hydrocarbon present in the exhaust. The octane rating of natural gas is about 120- 130 as compare to gasoline 87,meaning that engines could operate at compression ratio of up to 15.6:1 without "knock" or detonation. Due to higher C.R, CI engine can also use CNG as a fuel. But ascetane rating for CNG is poor, it cannot replace diesel totally like gasoline. According to poulton [4] natural gas has a low cetane rating, a spark ignition conversion for diesel engines is required, adding to the conversion cost.

Maintenance cost of gaseous fuel is lower than that for gasoline or diesel fuel engine, because gaseous fuel burn clean without emitting carbon deposits. Most importantly, natural gas significantly reduces CO_2 emissions by 20-25% compare to gasoline because simple chemical structures of natural gas (primarily methane – CH_4) contain one Carbon compare to diesel ($C_{15}H_{32}$) and gasoline (C_8H_{18})[4-8]

Table2.fuels characteristics [8]

Characteristics	CNG	Petrol	LPG
Formula	CH4	C4-C12	C3H8
Air-Fuel ratio	17.2	14.2	15.6
Octane rating	130	90-100	100
Auto Ignition	540	257	580
Higher heating value (MJ/kg)	49	43	45
Density (kg/m3)	2.52	749	0.72
Compression Ratio	9to12	9 to 12	8-12
Flame propagation speed(m/sec)	0.43	0.5	0.48
Adiabatic Flame Temp (K)	2266	2227	2810
Perches Cost (Rs/lit.)	21.30	67.71	15.06

Natural gas composition varies over time and from location to location [4]. Methane content is typically 70-90% with the remaining ethane, propane and carbon dioxide [9-10]. At atmosphericpressure and temperature, natural gas exists as a gas andhas low density. Since the volumetric energy density (joules/m3) is so low, natural gas is often stored in ahigh pressure vessel in compressed state. According to Poulton [4] that natural gas has a highoctane rating, for pure methane the RON=130 andenabling a dedicated engine to use a higher compression ratio to increase thermal efficiency byabout 10 percent above that for a petrol engine, although it has been suggested that optimized CNGengine should be up to 20 percent more efficient, although this has yet to be demonstrated. Compressednatural gas therefore can be easily used in sparkignitedinternal combustion engines. It has also a widerflammability range than gasoline and diesel oil[11]. CNG has low energy density, and hence it is compressed to a pressure of 200 to 250MPa to enhance the vehicle on-board energy storage. CNG is colorless, odorless, non-toxic, lighter than air and inflammable.

The use of natural gas in a diesel spark-ignition (SI) conversion is expected to allow engine life at least as good as original diesel engine. Because of its very lowenergy density at atmospheric pressure, roomtemperature and natural gas must be compressed and storedon the vehicle at high pressure - typically 20 MPa, 200bar or 2,900 psi. [7]. additionally, natural gas is neither the toxic, carcinogenic nor caustic [4]. According to[4] the legal maximum operating pressure for vehicle cylinder storage will usually be in the range 20 to 25 MPa -commonly 20 MPa. Cylinders are tested before giving a pressure of 30 MPa (300 bar or 4,350 psi) or to a level to meet local requirements. Safety regulations show a periodic re-inspection, typically at five-year intervals, including a pressure test and internal inspection for corrosion. According to [4] there are two refueling modes with CNG, the first is fast fill and the second is slow fill. Now the fast fill is where refueling times are comparable to those involved with conventional liquid fuels. Fast fill normally requires some high pressure (25MPa) storage at therefueling station although other way is to use a compressor sized to fill vehicles directly withoutintermediate (or cascade) storage. A typical mediumsizedrefueling station with a compressor output aroundof 300m3/hour would be capable of servicing 30 busesor 300 cars over a 12-hour period. The alternative storage method is inliquid form at a temperature of -162oC. Because of thelimited capacity of most CNG storage systemsa typical gas-fuelled vehicle will need refueling two to three times as similar petrol or diesel-fuelledvehicle - a typical CNG-fuelled car engine will providea range of 150-200 km and a truck some 300-400km. It is possible that the space required and weight ofCNG fuel storage systems will reduce in the future as a result of improved engine efficiencies as with dedicateddesigns and lightweight storage tanks[4].When a vehicle is operating on CNGabout 10 percent of the induced airflow is replaced bygas which causes a corresponding reduction in engine poweroutput. In performance terms the converted bi-fuelengine will generally have a 15-20 percent maximumpower less than that for the petrol version. When adiesel engine conversion is fuelled on gas more amount of enginepower can be obtained due to the excess air availablewhich, due to smoke limitations, is not fully consumed [7].A diesel/gas dual-fuelconversion may experience a loss of efficiency, relativeto diesel-fuelling alone. A 15-20 percent reduction in thermalefficiency was reported in a dual-fuel heavy-duty truckdemonstration in Canada, where natural gas provided60 percent of the fuel requirement during dual-fueloperation [4]. A further disadvantage of methane is that as itis a greenhouse gas with a warming forcing factor manytimes that of the principal greenhouse gas, CO2, Gasleakage or vehicular emission and the size ofrelease, will have an impact on the overall greenhousegas (GHG) emissions performance same to the petrolor diesel fuel it substitutes[9-12].

III. CNG FUEL EMISSIONS

The last and most often advantages have to do with pollution. The percentages vary depending upon the source, but vehicles burning natural gas emit lesser amounts of pollutants than petroleum powered vehicles.Nonmethanehydrocarbons are decreased by approximately 50%, NOx by 50-87%, CO2 by 20-30%, CO by 70-95% and the combustion of natural gas produces almost no particulate matter[7]. Natural gas powered vehicles emit no benzene and 1, 3-butadiene which are toxins emitted by diesel powered vehicles.Emissions of hydrocarbons mainly occur due to poor and incomplete combustion, because of incomplete mixing of fuel and air[7].The natural gas is a much simpler hydrocarbon than those in petrol and diesel and mixes non-uniformly with air, combustion is likely to be more complete in the time available fluids to inherently lower CO and non-methane HC emissions. Because a gas-fuelled does not require cold-start enrichment, emissions from cold engine operation are much higher thanwith liquid fuels and because gas systems are designed to be air-tight, so relative emissions should be negligible. Low sulphur content of natural gas is 5-10ppm; mainly from the odorant [4].At lower engine loads, combustible mixture is too lean to burn completely due to relatively lower flame propagation speeds, making HC emissions high. Also lack of oxygen in richer combustible mixture at higher engine loads increases HC levels in the exhaust. It is found that at lower BMEP i.e. low equivalenceratio, NO emission is lower, increases rapidly with increasing equivalence ratio (up to 0.9) and then the trend reverses. At lower engine load (BMEP), relatively lower combustion temperatures dominate over high oxygen concentration, resulting in lower NO levels [13].Emission of CO is strongly related to fuel-air mixture strength. The results show that for lower BMEP (i.e. low equivalence ratio) due to leaner mixture, CO emissions are very low (due to availability of excess oxygen); however they increase because of increasing equivalence ratio with formation of richer fuel zones (where sufficient oxygen is not available) leading to incomplete combustion .It is found that CO2 emissions increase with increasing BMEP and varies from 4- 8% (v/v). By comparing it with typical gasoline SI engine emissions, it can be seen that CNG DI engines produce about 20% lesser CO2 emissions [12] and this is due to lower carbon to hydrogen ratio of natural gas (1:4) compared to gasoline (typically ~2.3:1). The results also show that CO2 increases with retarded injection inspite of its inferiorcombustion characteristics.

IV. FACTOR AFFECTING THE SUITABILITY OF CNG AS AN ALTERNATIVE FUEL

Most of the engines are modified from the diesel engines to run on gas by introducing the gas governing, ignition, carburetion also changes in design by changing the compression ratio, valve timing, and changes in combustion chamber[13]. Before any alternative fuels could be used as an alternative to petrol or diesel, it has to fulfill some criteria. Stratton, Rosli Abu Bakar [15] has listed some suitability factors that would support alternative fuel to become a choice over petroleum fuels these factors are as follows;

- Fuel Reserves
- Refueling 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. PRESENT STATUS ON CNG ENGINES

In the diesel engines converted ordesigned to run on natural gas, there are two main options discussed. The first is dual-fuel engines. These are related to diesel engines operating on a mixture of naturalgas and diesel fuel. Natural gas has a low cetane ratingand therefore is not suited to compression ignition, but if a pilot injection of diesel occurs within the gas/air mixture, with normal ignition can be initiated. Between 50 and 75% of usual diesel consumption can be replacedby gas which when operating in this mode. The engine canalso revert to 100% diesel operation [7]. The second isdedicated natural gas engine, this is a specialized engine type, which has been designed and optimized to operate only on natural gas. This enables natural gas characteristics to be fully exploited without the need to compromise in design to enable other fuel usage.Until manufacturer Original Equipment (OE) engines are more readily available, however, thepractice of converting diesel engines to SI enginewill continue, which involves the replacement of dieselfuelling equipment by a gas carburetor and the additionof an ignition system and spark plugs [5].

For petrol engines or spark ignition engines two options are available, bi-fuel conversion anduse a dedicated to CNG engine. The bi-fuel type of engine development is dependent on the conventional petrol engines where the fuel system has been modified to operate either petrol or gas. Now when natural gas refueling is not available, normal running on petrol is possible. The bi-fuel engines of the spark ignition petrol engines according to Poulton[4] is of all sizes can be converted to natural gas by the fitting of a gas carburetor / mixer, regulator, shut-off valves, control system and fuel storage tanks .Dedicated natural gas engines according Semin.[7]is the engine dedicated to mono fuelof natural gas engines, there are optimized for thenatural gas fuel. They can be derived from petrolengines or may be specifically designed for the purpose.

According to Semin.[7]Buses and trucks larger and greater numbers ofcylinders are used than for light-duty engines. Forcompression ignition engines conversions to sparkignition, the pistons must be modified to lower theoriginal compression ratio and a high-energy ignitionsystem must be fitted. The system is suitable for CNGand is ideally suited to time (sequential) port injectionsystem but can also be used for single point and lowpressure in-cylinder injection. An approximate measure of the equivalent petrol ordiesel fuel capacity of a cylinder filled with gas at 20 Map is obtained by dividing the cylinder volume by 3.5 - thus a 60-litre cylinder will provide the energy equivalent of 17 liters of conventional fuel [4].

M. U. Aslam et al[2006][16] carried out the experiment on a 1.5 L, 4-cylinder Proton Magma retrofitted spark ignition engine with dynamometer. The engine was converted to computer integrated bi-fueling system from a gasoline engine and thus was operated separately either with gasoline or CNG using an electronically controlled solenoid actuated valve system. Then 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. This engine shows an average of 2.90% higher FCE nearly at

IJARSE
ISSN 2319 - 8354

stoichiometric air–fuel ratio (lZ1) with CNG at WOT condition and this higher value reduces with the decrease of l value. On average retrofitted engine reduced CO by around 80%, CO2 by 20% and HC by 50% and high amount ofNOx emissions by around 33% with CNG compared to gasoline.

M. A. Kalam[17]carried out an experiment on DOHC 16V 4 cylinder inline engine.The engine is controlled by CADET12 engine controlled software from the computer. The coriolis micro motion mass flow meter was used to measure CNG flow rate into engine. The horiba exhaust gas analyzer was used to measure emission concentration for CNG-DI engine. All the results obtained from experimental tests arediscussed as follows:

5.1 Brake power at Wide Open Throttle [WOT]

Figure 1 shows engine speed versus brake power from 1500 rpm to 6000 rpm for all the test engines such as “Gasoline-PI”, “CNG-BI” and CNG-DI engines at WOT. It is observe that gasoline-PI,CNG-BI and CNG-DI produce maximum brake power at 6000 rpm which are 70.21 kW, 57.35 kW(at 5500rpm) and 73.04 kW respectively. The CNG-DI engine produce 23% higher break power than CNG-BI engine. The reason of producing lower brake power by CNG-DI engine than gasoline is that low volumetric efficiency, inlet gas temperature air fuel ratio as well as cylinder pressure.

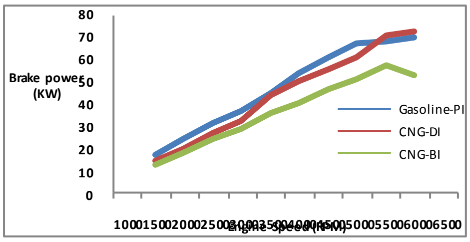

Fig1. Engine speed versus brake power at WOT

5.2 Brake torque at WOT-

Figure 2 shows engine speed versus brake torque from 1500 rpm to 6000 rpm for allthe test engines like “Gasoline-PI”, “CNG-BI” andCNG-DI engines at WOT. It is observe that gasoline-PI, CNG-BI and CNG-DI produce maximum torqueare 128.42 Nm (at 4500 rpm), 100 Nm (at 4500 rpm) and123.47 Nm (at 5500 rpm) respectively .The reason ofproducing lower brake torque by CNG-DI engine than gasoline ismainly due to lack of chemical energy conversion tomechanical energy having strongly related to volumetricefficiency, net heat release andcylinder pressure. Improper cylinder pressure such astoo low cylinder or too high pressure causes lower brake torque.

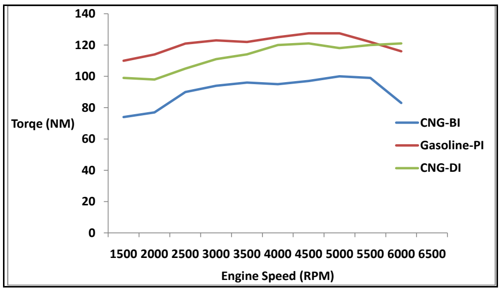

Fig 2. Engine speed versus brake torque at WOT

5.3 specific fuel consumption at WOT

Figure 3shows the variation of brake specific fuel consumption(BSFC) versus engine speed for test engines from1500 rpm to 6000 rpm at WOT. It is found that theBSFC increases initially at 1500 rpm for all the enginesdue to increase in magnitude of friction, pumping workand the increased relative importance of friction and heattransfer, which decreases the gross indicated fuel conversion efficiency. It is found that "Gasoline-PI" engine reduces SFC from 1500 rpm to 3500 rpm due to increasing fuel conversion efficiency and then started to increase SFC due to increase in frictional effect with increasing engine speed. The lowest SFC (243.34 g/kWh) comes from the CNG-DI engine at 3500 rpm which is followed by "Gasoline-PI" (254.87 g/kWh@3500 rpm) and "CNG-BI" (264.11 g/kWh@3500rpm) engines.

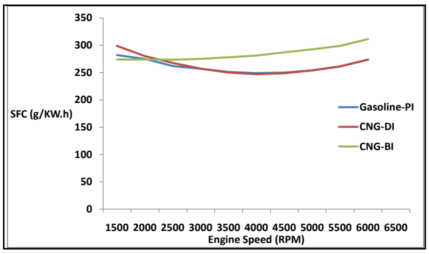

Fig3.Brake Specific Fuel Consumption versus Engine Speed at WOT

5.4 Unburned hydrocarbon at WOT

Unburnedhydrocarbon or partially oxidized hydrocarbon emissionincreases if (a) the injection occurs too early, in whichcase the delay time thus increases with the result that morefuel goes to contact at the relatively cool cylinder wall, or(b) injection late in which case there may beless time for completion of combustion. The latercase may be matched with CNG-DI engine as the directinjection cooled gas entering into engine cylinder, whichis the main reason for getting high HC emission ascompared to "gasoline-PI" engine. It is found that,the average HC emissions over theentire test cycle were 137 ppm, 102 ppm and 203 ppmby CNG-DI, "Gasoline-PI" and "CNG-BI" respectively.The CNG-DI engine produces slightly higher (by 34%)than the base engine "gasoline-PI".

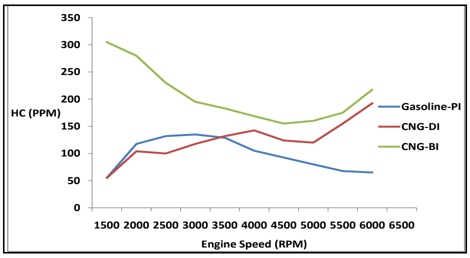

Figure4. Unburned Hydrocarbon Versus Engine Speed at WOT.

5.5 Oxides of nitrogen at WOT

The NOx concentration versus engine speed is shown in Fig. 5. It was found that the lowest NOx wasproduced by "CNG-BI" (average 489 ppm) which is followed byCNG-DI (809 ppm) and "gasoline-PI" (1526 ppm) engine.It is very interesting that the CNG-DI reduces (50%) NOx emissions as compared to base engine "gasoline-PI".This are mainly because of cool gas entering into enginecylinder, so that the overall combustion is completed atlow in cylinder temperature.

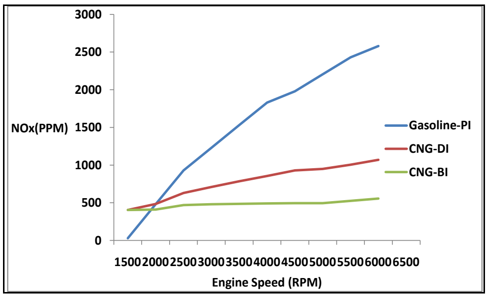

Fig5. Oxides of Nitrogen versus Engine Speed at WOT

5.6 Carbon monoxide at WOT

Carbon monoxide (CO) isformed during the combustion process having rich fuel-airmixtures and when there is insufficient oxygen to fullyburn all the carbon in the fuel to CO2. As CO is related to rich fuel-air mixtures, hence spark ignitionengine is the significant sources for CO emission,because they have stoichiometric or close tostoichiometric air-fuel ratio which may divide into fuel richzone and fuel lean zone in the cylinder duringcombustion. Over the test cycle, it can be seen that “CNG-DI”engine produces higher CO (2.01%) emission followedby “CNG-BI” (1.31%) and gasoline-PI (1.11%) engine.

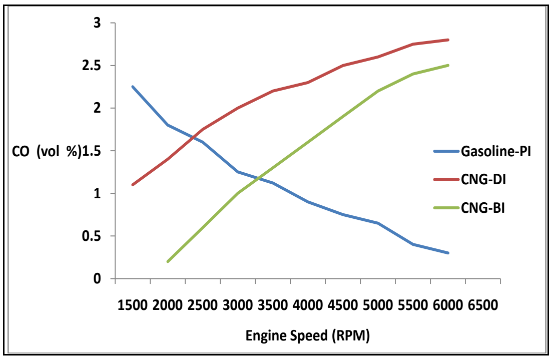

Fig6. Carbon Monoxide versus Engine Speed atWOT

VI. CONCLUSION

Based on the review paper of the performance and emission of compressed natural gas, it is concluded that natural gas represents a good alternative fuel for internal combustion engine and therefore must be taken into consideration in the future for transport purpose.

The number of conclusion taken from study of experimental result is given below:

1) Non methane hydrocarbon is reduced by approximately 50%,NOx by 50-87%, CO2 by 70-95% and there is no particulate made in exhaust.

2) It has better combustion properties over the gasoline and diesel fuel.

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