KIGAS Vol. 15, No. 4, August, 2011
(Journal of the Korean Institute of Gas)

The Performance and Emissions Analysis of a Multi Cylinder Spark Ignition Engine with Gasoline LPG & CNG

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(Received January 28, 2011; Revised August 19, 2011; Accepted August 19, 2011)

Abstract - The introduction of alternative fuels is beneficial to overcome the fuel shortage and reduce engine exhaust emissions. LPG and CNG are relatively clean fuel and considered as most promising alternative automotive fuels worldwide because of its emission reduction potential and lower fuel price compared to gasoline. Now a day's adaptation of dual fuel approach is the growing as common trend. The two fuels can be successfully implemented with existing gasoline engine with little modification. The present study was done to analyze the performance and emissions analysis of a multi cylinder spark ignition engine fuelled with the benefits of CNG and LPG aseffective alternate automotive fuels by simply using them in an unmodified petrol engine. The test results indicate, the energy content of CNG and LPG is the most limiting factor in acceptance for fuel economy and performance reasons. Thermal efficiency was high for CNG lowest for gasoline and LPG between the two. BSFC, CO and HC were low and NOx was high for CNG and low for gasoline, LPG lies between the two.

Key words : alternate fuel, spark iginition engine, natural gas etc.

1. INTRODUCTION

The world is moving towards a sustainable energy era with major emphasis on energy efficiency and use of renewable energy sources (Chauhan *et al.* 2010). Concerns on the long-term availability and environmental issues regarding emissions from conventional fuels such as gasoline and diesel are of serious concern. Because of ever rising cost of fossil fuels and limited reserves of the fossil fuel, development of alternative fuel engines has attracted more and more attention from the engine community.

Based on these criteria, several alternate fuels have been considered as viable and economical substitutes for conventional fuels such as gasoline and diesel with natural gas (CNG/LNG), propane (LPG), DME, ethanol, bio-diesel, hydrogen, methanol etc. In the present context LPG, CNG, and otherhydrocarbon fuels are considered among the short term alternatives as they are finite in nature and are derived from sources that are themselves finite and considered as first choice to overcome energy shortage. These fuels have emerged as a cost effective alternatives to both gasoline and diesel. The constraining factors in any country remain building the requisite infrastructure for large scale implementation of these fuels and safety aspects which are of utmost importance while handling these fuels. McDade (2004) studied the role of LPG in poverty reduction and growth there is ample evidence that improved,affordable and safe fuels for use in households and small industry not only improve human health and the situation of women, but directly contribute to improved living conditions when linked to income-generating activities. Much greater efforts are needed to improve the efficiency of traditional biomass use. The Chinese government has enacted policies to promote alternative vehicle fuels (AVFs) and alternative fuel vehicles (AFVs), including city bus fleets (Ou *et al.* 2010). Yeh, Sonia (2007) studied the adoption of alternative fuel vehicles (AFVs) has been regarded as one of the most important strategies to address the issues of energy dependence, air quality, and, more recently, climate change in Argentina, Brazil, China, India, Italy, New Zealand, Pakistan, and the US. Environmental

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benefits of reducing local air pollution was observed when diesel buses were replaced by natural gas vehicle which havethe potential to emit lower level of exhaust emissions as compare to fossil fueled vehicle (Goyal and Sidhartha, 2003). The inclination of world towards the increased used of CNG and LPG as SI engine fuel. The present study was done to analyze the performance and emissions analysis of a multi cylinder spark ignition engine fuelled with the benefits of CNG and LPG as alternate automotive fuels by simply using different load conditions(unmodified petrol engine. gasoline, CNG and LPG).

2. LPG AND CNG AS A CLEAN FUEL

Liquefied Petroleum Gas (LPG) is a mixture of low-boiling hydrocarbons that exists in a liquid state at ambient temperatures when under moderate pressures (less than 1.5 MPa or 200 psi). LPG is a by-product from the processing of natural gas and from petroleum refining. Major components of LPG are propane (C_3H_8), butane (C_4H_{10}) and propylene (C_3H_6). LPG has a simpler molecular structure and its carbon to hydrogen ratio is low resulting in lower emissions. It is gaseous at normal temperatures and pressures. It is odorless, therefore for safety reasons ethyl mercaptan is added to make any leaks detectable. High octane rating (105)of LPG allows compression ratio and thereby efficiency increased (Willson B, 1992). It is considerably cheaper to run a vehicle on LPG rather than on Gasoline. In the times of ever increasing prices of gasoline, running one's vehicle on LPG gives enormous savings.

Physically, natural gas is colorless, tasteless, and relatively non-toxic. It exists in our environment at normal temperature and pressure, which gave it its name. To use natural gas as fuel in vehicles, it has to be compressed at a high pressure of about 18- 20MPa at normal temperature in vessels before it can be supplied to the engine's combustion chamber. Generally, natural gas is lighter than air with a vapor density of 0.68 relative to air. Therefore, if leaking happens, it will not cause explosion but instead it will disperse to the atmosphere. Natural gas has a high auto-ignition temperature compared to gasoline or diesel, which is the lowest temperature for it to ignite through heat alone and without any spark or flame. Higher ignition temperature means that natural gas is more difficult to ignite. This can significant reduce the fire hazard, and constitute anti-knocking ability especially when it is compressed in a very high pressure in the combustion chamber. This property is certainly useful for the design of a dual-fuel engine. The ignition temperature for natural gas is about 900 K. For natural gas, the octane number is approximately 120. This is much higher than gasoline with an octane number of 95. This property is important as it determines the time needed for the natural gas and air to mix homogeneously in the combustion chamber to minimize knocking or detonation. The standard physico- chemical properties of the three fuels are shown in table 1.

Natural gas is cheaper "at the pump" than gasoline and diesel fuel. Prices vary around the country. Vehicle operating costs are reduced by as much as 70% by using CNG instead of Gasoline. Since hydrogen is a gas, hydrogen powered vehicles will require changes in a number of areas, including building codes and standards, mechanic/ inspector/user training. NGVs require many of the same changes. Therefore, a growing NGV market today is smoothing the path for a hydrogen vehicle market tomorrow.

Table 1 Physico-chemical properties of fuels

Properties	Petrol	LPG	CNG
Chemical composition	C4toC10	C3toC4	CH4
Specific density at 15^0C(kg/litre)	0.73	0.54	0.14
Boiling point at 1 bar (^{0}C)	25 to 110	-50 to 0	-162
Lower heating value (MJ/kg)	43.5	46.1	47.7
Ignition temperature in air (^{0}C)	220	400	540
Lower ignition limit (vol % gas)	0.6	1.5	5
Upper ignition limit (vol % gas)	8	15	15
Stoichiometric air/fuel ratio (kg/kg gas)	14.8	15.5	17.2
Fuel octane rating RON	95	105	120
Fuel octane at 25^0C(bar)	82	97	120

3. EXPERIMENTAL SETUP

The setup consists of four cylinder, four stroke, gasoline (MPFI) engine connected to eddy current type dynamometer for loading. The schematic diagram of the experimental is shown in fig.1 and the specification of the engine is as shown in Table 2. It is provided with necessary instruments for measurements of combustion pressure and crank angle. These signals are interfaced to computer through engine indicator for diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The set up has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air andfuel flow measurements, process indicator and engine indicator. Rota meters are provided for cooling water and calorimeter water flow measurement. The main aim of this experiment is to investigate the effects on performance and emissions with Gasoline, CNG and LPG in a four cylinder MPFI gasoline engine. A CNG Conversion Kit and a LPG Conversion kit were installed on the engine with an arrangement for changeover from one fuel to another. For compression ratio (CR), higher CR may be used to take advantage of higher octane number. Valve seat, head gasket etc. are to be changed. For valve timing, Exhaust valve must open late in power stroke. Ignition timing needs to be advanced. For ignition system, ideally NG requires more energy for ignition, so stronger spark plug is required. All results have been measured before catalyst converter.

Table 2. Engine specification

Engine type	MPFI, 4 Cylinder, 4 Stroke
Maximum output Power	44.5kw at 6000 rpm
Maximum torque	59 Nmat 2500rpm
Stroke x Bore	61mm x72mm
Compression ratio	9.4:1
Displacement	993 CC

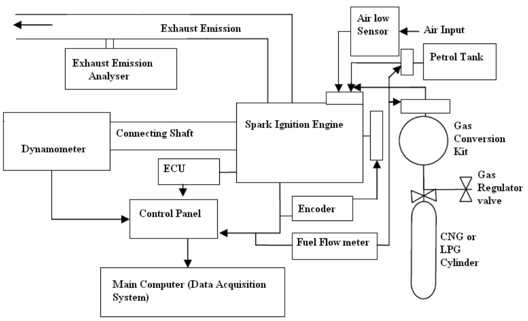

Fig. 1. Experimental setup.

4. RESULTS AND DICSUSSION

Thermal efficiency is the measure of the efficiency and completeness of combustion of the fuel. As the brake power increases, there is considerable amount of increase in brake thermal efficiency for all fuel. Brake thermal efficiency of CNG during whole range is high, gasoline is low and LPG lies between the two. Thermal efficiency increases in CNG fuelled engine due to higher CNG calorific value. This is due to reduction in short-circuiting losses and increase in air-fuel ratio. This indicates that the engine can operate in leaner air-fuel ratios without loss of power. This is achieved because of the precise timing and metering of the fuel by the microcontroller fuel injection system. Brake thermal efficiency increases from lean to rich and starts decreasing at engine rich mixtures. For the same equivalence ratio, the carbureted engine gives lesser brake thermal efficiency compared to the injected engine. This is due to incomplete combustion of the charge due to

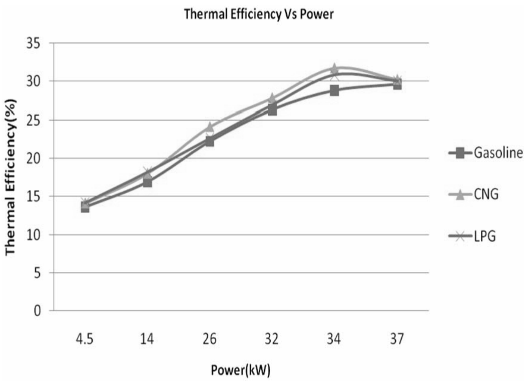

Fig. 2. Test result of brake thermal efficiency with power.

mixture limit inside the combustion chamber at a given compression ratio. Hence, the amount of fuel charge to give the mechanical power gets reduced and thus reduces the brake thermal efficiency.

Brake specific fuel consumption (BSFC) is the ratio of the engine fuel consumption to the engine power output. The variation of gasoline, LPG and CNG operation is shown in Figure 3. The brake specific fuel consumption is low for CNG and high for gasoline and LPG lies between the two. This can be explained by the facts that heating value of CNG is 12% higher than that of gasoline and it produced a comparable but Higher output brake power (BSFC is inversely proportioned to brake power) and LPG between the two. It is mainly due to CNG consumes less energy per unit power produced compared to gasoline under the same engine operations and configurations. The BSFC of natural gas has been measured lower than that of gasoline. This fact is attributed to the higher heating value and leaner combustion of CNG compared to gasoline.

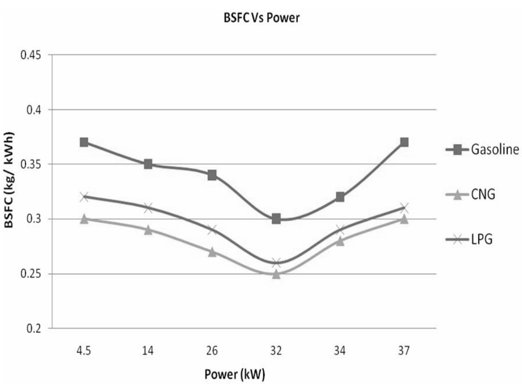

Fig. 3. Test result of brake specific fuel Consumption (bsfc) with power.

The variation of CNG, LPG and gasoline is shown in Figure 4. The amount of CO is a function of air-fuel ratio. In fact, as air-fuel ratio gets closer to stoichiometric condition, the amount of CO emission becomes less. The air-fuel ratio of CNG fuelled engine is closer to stoichiometric condition; consequently CO emissions aredecreased with CNG. It was found that CNG produced less20-98% of CO. CO is a result of incomplete combustion in engine and is generated when the engine is operated with a rich mixture or when proper air-fuel mixing is not achieved. With high hydrogen-to-carbon ratio and its simpler chemical structure, it is expected CNG (predominantly CH_4) produces lower CO and CO2 than gasoline (C8H18). Higher propane content LPG will have higher vapor pressure, allowing later injection timings, and reduced fuel short-circuiting. The amount of CO2 in combustion of hydrocarbons is proportional to carbon to hydrogen ratio. The main component of natural gas is methane which has the lowest carbon to hydrogen ratio compared to other hydrocarbons. Therefore, the resulting CO_2 in CNG combustion is less than gasoline and for LPG lies between the two.

The variation of hydrocarbon (HC)with power is shown in fig. 5. There are some reductions in the HC concentration with CNG and LPG operation. These reductions are due to higher temperatures of combustion

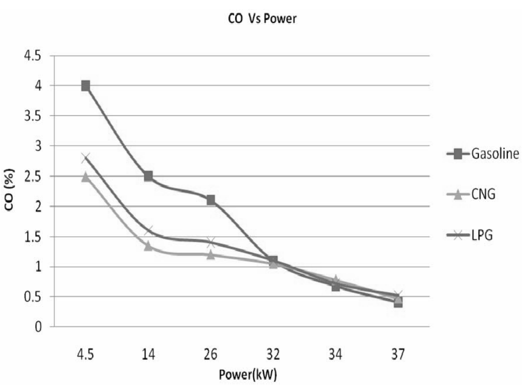

Fig. 4. Test result of CO with power.

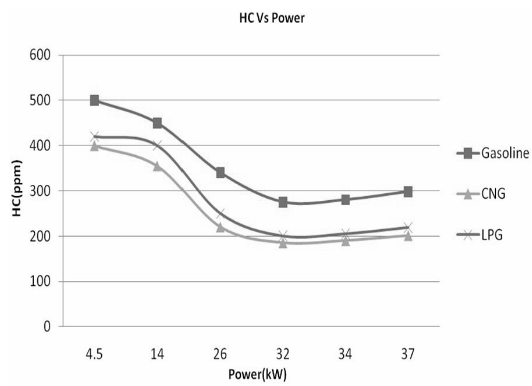

Fig. 5. Test result of HC with power.

and exhaust gases and lower fuel trapping phenomenon in crevices while engine operates with CNG and LPG. A comparison of raw HC emissions in ppm can therefore be deceptive as molecular weight of the emissions from the CNG or LPG fueled engine is much lighter than the gasoline. The major reason is because of fuel composition, Any incompletely vaporized liquid fuel, either in the form of suspended droplets or wall films, may not completely burn, any wind up contributing to the HC emissions of liquid fueled engines. The bulk of the HC emission from both premixed versions, however, is due to short-circuiting of the fuel during scavenging. Gasoline HC emissions may cool and condense out resulting in visible smoke, while CNG which is CH_4 and LPG HC emissions, predominantly propane or butane, remain as a gas. As shown in the figure, the NOx emissions drop in higher loads for gasoline fuel. According to ECU strategy when engine load rises, more liquid fuel is injected into combustion chamber. Evaporation of this increased amount of liquid fuel reduces combustion chamber temperature and consequently NOx emissions. Whereas, in the engine fuelled by CNG there is no cooling effect of fuel evaporation and NOx emissions rise in higher loads. For both fuels, NOx emissions grow at higher engine power because combustion period is shortened and the O and N radicals don't have enough time to react.

Figure 6 shows the variation of NOx for three fuels with change in power. According to the obtained results, the NOx emissions are increased with CNG fuel as compare to LPG and Gasoline. NOx emissions are high due to combustion temperature and the local air fuel ratioin the mixture for CNG and LPG than gasoline. Due to the elimination of the cooling effect of liquid fuel vaporization more spark advance which is used to compensate for lower natural gas or LPG flame speed propagation which results in the rise of combustion temperature.

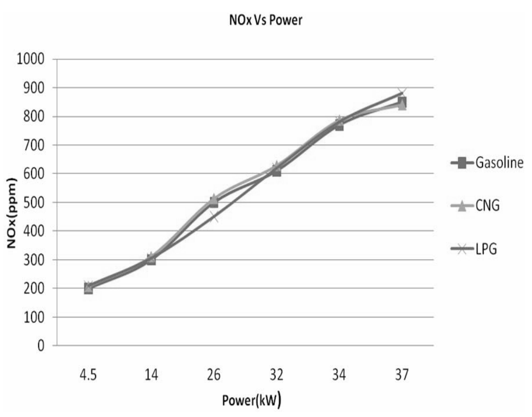

Fig. 6. Test result of NOx with power.

5. CONCLUSIONS

1) The object of this study was the behavior of performance and emissions characteristics of a multi-cylinder gasoline engine with the benefits of CNG and LPG as alternate automotive fuels by simply using them in an unmodified petrol engine.

2) Both fuels have high octane number than gasoline fuel. Engine tests were done in steady state part load and full load conditions for CNG, LPG and gasoline fuels.

3) The test results indicate, the energy content of CNG and LPG is the most limiting factor in acceptance for fuel economy and performance reasons. The results of Thermal Efficiency vs. Power show that gasoline gives the most optimum thermal efficiency, closely followed by CNG and LPG. Optimum performance is achieved by using gasoline.

4) Considering the trend of BSFC vs. Power for the three fuels it is observed that CNG gives the lowest BSFC than Gasoline and LPG even when used to run an engine designed for gasoline, although it increases somewhat at very high power.

5) By using alternate fuels as LPG and CNG results in emissions reduction in form of CO and HC emissions. The NOx emissions are the only ones that show an increase in their amounts. Therefore for engines designed to run on gasoline, LPG and CNG can be close substitutes.

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