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PERFORMANCE AND EMISSIONS OF ALTERNATIVE FUELED INTERNAL COMBUSTION ENGINE: A REVIEW

Albela H.Pundkar

Asst.Professor, G.H.Raisoni institute of Engineering & Technology, Pune., MS (India)

ABSTRACT

The increasing industrialization and transportation of the world has lead to a steep rise in the demand of petroleum based fuels. Petroleum based fuels are obtained from limited reserves. These finite reserves are highly concentrated in certain regions of the world and therefore to fulfill the demand of the rest of the regions they have to import the crude petroleum for the power production and industrialization. On the other hand the emissions from the fossil fuels are considered as a major source to the environment pollution and have an adverse effect on human health. Hence it is necessary to look for alternative fuels which can be produced from the available local resources and that could reduce the dependence on petroleum. Alternative fuels like LPG, CNG, hydrogen etc has emerged as a solution to depleting crude oil resources as well as to the deteriorating urban air quality problem. As a gaseous fuel, gains from LPG have already been established in terms of low emissions of carbon monoxide, hydrocarbon. Air-fuel ratio, operating cylinder pressure ignition timing and compression ratio are some of the parameters that need to be analyzed and optimally exploited for better engine performance and reduced emissions. In the present paper a comprehensive review of various operating parameters and concerns have been prepared for better understanding of operating conditions and constrains for a LPG fueled internal combustion engine.

Keywords: LPG, VCR Spark Ignition Engines, Dual Fuel Engine, Combustion Characteristics, Performance Characteristics And Emissions.

I. INTRODUCTION

The Energy comes in a variety of renewable forms like wood energy, wind energy, solar energy, ocean water power, geothermal energy; bio energy generated by bio fuels is viewed as a strong source of energy in the coming years. The Energy is also available in the non-renewable form of fossil fuels that is oil, natural gas and coal, which provide almost 80% of the world s supply of primary energy. Use of these fossil fuels is a major source to cause pollution of land, sea and the entire atmosphere. For the last two centuries it is coming to know that all the unprecedented industrialization, power productions and transportation are mainly driven by fossil fuels and they have changed the face of this planet. India is the fourth largest consumer of energy in the world after USA, China and Russia, but it is not endowed with abundant energy resources. Despite the recent global economic slowdown, India s economy is expected to continue to grow at 6 to 8 percent per year in the near term, the strong economic growth and a rising population, growing infrastructural and socioeconomic development will stimulate an increase consumption across all major sectors of indian economy, India imports about 80% of its crude oil requirement for domestic production of oil is inadequate to keep pace with the rising consumption of petroleum products. The indiscriminate extraction and consumption of fossil fuels results in a reduction of petroleum reserves and also the emissions from the fossil fuels are considered as a major source to the environment pollution. Hence there is a need to find some alternate fuel, which can provide compensation for the depletion of the conventional petroleum resources and which can be produced from the available local resources. alternative fuels are alcohol, ethanol, biodiesel, vegetable oils etc. the main alternatives are currently road fuel gases LPG and CNG bio-fuels and, more distantly, hydrogen fuels, including methanol; fuel cells, and electric vehicles. KirtiBhandari et.al LPG as a fuel for spark ignition engines, it has many of the same advantages as natural gas with the additional advantage of being easier to carry aboard the vehicle. Its major disadvantage is the limited supply, which rules out any large-scale conversion to LPG fuel. LPG is typically a mixture of several gases in varying proportions. Major constituent gases are propane (C3H8) andbutane (C4H10), with minor quantities of propane (C3H6), various butanes (C4H8), iso-butane, and small amounts of ethane (C2H6). The composition of commercial LPG is quitevariable. Being a gas at normal temperature and pressure LPG mixes readily with air in any proportion. Figure 1 shows that about 55% of the LPG processed from natural gas purification.The other 45% comes from crude oil refining. LPG is derived from petroleum, LPG does less to relieve the country dependency on foreign oil than some other alternative fuels.LPG does help address the national security component of the nation s overall petroleum dependency problem. To benefit from the use of LPG in IC engines, it is necessary to understand its combustion under the appropriate conditions and to study the effects of various parameters on it. This review aims to prepare a concise state of art that provides an idea of various concerns related to employment of LPG as a vehicular fuel in order to improve the rapidly deteriorating air quality conditions in urban regions. Comparative Properties of LPG, Gasoline as follows.

Table 1 Comparative Properties of LPG, Gasoline as follows.

Properties/Fuels	**Gasoline**	**LPG**
Chemical Structure	C7h17/C4 To C12	C3h8
Energy Density	109,000-125,000	84,000
Octane Value	86-94	105+
Lower Heating Value (Mj/Kg)	43.44	46.60
High Heating Value (Mj/Kg)	46.53	50.15
Stoichiometric Air/Fuel Ratio	14.7	15.5
Density At15˚C,Kg/M3	737	1.85/505
Autoignition Temperature ^{O}k	531	724
Specific Gravity 60° F/60°	0.72-0.78	0.85

As the gaseous fuel requires 4 to 15 percent of more intake passage volume than liquid fuels which reduces the VE and hence maximum power output will also be reduced(by 4%). SI engines burn a premixed air-fuel

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mixture followed by compression before a spark ignites the mixture. Octane rating of a fuel indicates how slowly the fuel will burn and how well the fuel will resist pre-ignition before the spark plug fires. Higher octane fuels can be burned at high compression ratios (CR). The higher CR of an engine, the more efficient is the engine and more is the power generated with given amount of the fuel. LPG has high octane rating 110+ that allows CR to be high up to 15:1, which is in the range of 8:1 to 9.5:1 for gasoline engines.

II. LPG AS AN ALTERNATIVE FUEL FOR IC ENGINE

The gaseous nature of the fuel/air mixture in an LPG vehicle s combustion chambers eliminates the cold-start problems associated with liquid fuels. LPG defuses in air fuel mixing at lower inlet temperature than is possible with either gasoline or diesel. This leads to easier starting, more reliable idling, smoother acceleration and more complete and efficient burning with less unburned hydrocarbons present in the exhaust. In contrast to gasoline engines, which produce high emission levels while running cold, LPG engine emissions remain similar whether the engine is cold or hot. Also, because LPG enters an engine s combustion chambers as a vapor, it does not strip oil from cylinder walls or dilute the oil when the engine is cold. This helps to have a longer service life and reduced maintenance costs of engine. Also helping in this regard is the fuel s high hydrogen-to-carbon ratio (C_3H_8), which enables propane- powered vehicles to have less carbon build-up than gasoline and diesel-powered vehicles. LPG delivers roughly the same power, acceleration, and cruising speed characteristics as gasoline. Its high octane rating means engine s power output and fuel efficiency can be increased beyond what would be possible with a gasoline engine without causing Destructive Knocking. Such fine-tuning can help compensate for the fuel s lower energy density.

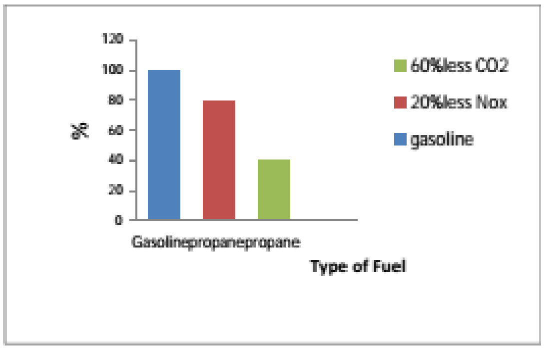

Fig.1 Vehicle Emissions

The higher ignition temperature of gas compared with petroleum based fuel leads to reduced auto ignition delays,less hazardous than any other petroleum based fuel and expected to produce less CO, NOx emissions and may cause less ozone formation than gasoline and diesel engines.

III. ENGINE MODIFICATIONS REQUIRED

Many propane vehicles are converted gasoline vehicles the relatively inexpensive conversion kits include a regulator/vaporizer that change liquid propane to a gaseous form and an air/fuel mixer that meters and mixes the fuel with filtered intake air before the mixture is drawn into the engine s combustion chambers. Also included in conversion kits is closed-loop feedback circuitry that continually monitors the oxygen content of the exhaust and adjusts the air/fuel ratio as necessary.LPG vehicles additionally require a special fuel tank that is strong enough to withstand the LPG storage pressure of about 130 pounds per square inch.

IV. ENGINE TECHNOLOGY FOR LPG VEHICLES

As the LPG is stored in liquid form under high pressure,it is need to convert it into vaporized form before drawn into the combustion chamber. As engine technology for LPG vehicles is similar to that for natural gas vehicles, with the exception that LPG is not commonly used in dual-fuel diesel applications due to its relatively poor knock resistance *Hutcheson1995[21]*.For Spark ignition engine there are two types of LPG engines are primarily studied

1. LPG which is stored in composite vessel at high pressure approximately at 10-20 bar ,supply to the engine is controlled by a regulator or vaporizer, which converts the LPG to a vapor. The vapour is fed to a mixer located near the intake manifold, where it is metered and mixed with filtered air before being drawn into the combustion chamber where it is burned to produce power, just like gasoline.
2. LPG fueled direct injection SI engine, especially in order to improve the exhaust emission quality while maintaining high thermal efficiency comparable to a conventional engine. In-cylinder direct injection engines developed recently worldwide utilizes the stratified charge formation technique at low load, whereas at high load, a close-to-homogeneous charge is formed.

V. CURRENT STATUS OF LPG ENGINES: PERFORMANCE AND COMBUSTION CHARACTERISTICS

Following literature survey is done to study the present status of LPG engines performance and combustion characteristics *Shinichi Goto 2000* has been carried out to investigate the effect of various piston cavities and swirl ratio on combustion characteristics as well effect of fuel composition on engine performance with a single cylinder research engine (Nissan Diesel Co. FD1L.From the results he found that Lean burn operation of an LPG SI engine resulted in improved fuel consumption for both the full and half load cases.

G.H.Choi et.al 2002 carried out to quantify the combustion and emissions characteristics of LPG fuelled SI engine with minor modification in original SI engine to run on LPG fuel with varying volume percentage of LPG at 5%,10%,20% with the help of PLC controller. Engine speed maintained at 4000rpm,the relative air-fuel ratio varies from 0.8 to 1.3.The exhaust gas constituents (CO_2,CO,uHC and NOx) were measured using the 5-gas analyzer. Percentage of LPG in gasoline means that the combustion shifted towards complete phase and greener exhaust products were subsequently released to the atmosphere. For each proportion of LPG in gasoline investigated, it was also observed that the CO_2 emissions peaked at around $\lambda=1$ and exhibits lower percentages at rich and lean mixtures. An increasing proportion of LPG in gasoline promotes faster burning velocity of mixture and hence reduce the combustion duration and subsequently the in-cylinder peak temperature increases. At high relative air-fuel ratio, the amount of NOx measured was much higher, uHC also shows marked reduction as the relative air-fuel ratio exceeds Stochiometric.

Ki hyung Lee et.al 2005 study to clarify the combustion process of the heavy duty LPG engine, the flame propagation and combustion characteristics were investigated using a CVCC and a port injection type heavy duty LPLi engine system. Both the laser deflection method and the high-speed Schlieren photography method were employed to measure the flame propagation speed of LPG fuel. In addition, the single cylinder heavy duty LPLi engine was manufactured to analyze the combustion characteristics of the LPG.

M.A. Ceviz, F.Yuksel 2006 compare the cyclic variability and emission characteristics of LPG and gasoline-fuelled spark ignition engine at lean operating conditions. Cylinder pressure, indicated mean effective pressure (imep), mass fraction burned (MFB) and combustion duration are presented in relation to cyclic variability. Variations in the CO, CO_2 and HC emissions are also discussed. The lean operation decreases the flame speed and the burning rate, result in an increase in the overall combustion duration, However, the increases in the combustion duration when in operation with LPG is lower than that of gasoline despite working on more lean conditions. The reason for the lower combustion duration is the higher laminar burning velocity of LPG (0.46 m/s) when compared with gasoline (0.42m/s) and lowered the emission also.

*Orhan Durgun et.**al**2007* Studied a quasi-dimensional spark ignition (SI) engine cycle model is used to predict the cycle, performance and exhaust emissions of an automotive engine for the cases of using gasoline and LPG. Combustion is simulated as a turbulent flame propagation process and during this process, two different thermodynamic regions consisting of unburned gases and burned gases that are separated by the flame front are considered. A computer code for the cycle model has been prepared to perform numerical calculations over a range of engine speeds and fuel air equivalence ratios. Comparisons show that if LPG fueled SI engines are operated at the same conditions with those of gasoline fueled SI engines; significant improvements in exhaust emissions can be achieved.

*R.K. Mandloi et. al(2010) s*tudies the use LPG instead of gasoline. Result shows that LPG reduces the engine volumetric efficiency and, thus, engine effective power. LPG decreases the mole fractions of CO and NO included in the exhaust gases. But in Long term continuous use of auto- LPG causes thermal Pitting of engine the part which leads to increase engine pollution. Along with this it was suggested that structural failure may take place due high cylinder pressure and temperature.

C-L Myung,SPark,JKim,KChoi,I G Hwang 2011 focuses on the experimental comparison of combustion phenomena and nanoparticle emission characteristics from a wall-guided DI spark ignition engine for gasoline and LPG. A returnless GDI fuel supply system was reworked for the return-type liquid-phase

From the above literature review showed the improved combustion characteristics, performance and emissionscharacteristics with LPG as alternative fuel to gasoline at various condition such as changing the piston cavities, air fuel ratio, speed etc.Further research has to be carried out by changing compression ratio/ignition timing to compare the performance and emissions characteristics.

VI. NOISE AND AIR POLLUTION WITH LPG ENGINES

The study of engine noise has been carried out since the early stages of engine development. In 1931, Ricardo first found a descriptive relationship between the combustion pressure rise and the noise produced . Later, a number of parameters in determining the noise developments were investigated which include the first and the second derivative of cylinder pressure . These methods were effective in revealing the relationship between engine combustion and noise. Some of them still play an important role in identifying the source of engine noise *Ando. H.et.al.* Although there are a number of engine noise sources, one of the most

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fundamental is the combustion-induced noise. It occurs toward the end compression stroke and subsequent expansion stroke. The rapid pressure change due to the combustion transmits through engine structures and forms a part of the airborne noise . This pressure change also causes the vibration of the engine components. Because of its superior knock-resistance, propane is preferred to butane as an automotive fuel. Graph shows IANGV emissions comparison study between Gasoline, LPG and CNG. Switching from gasoline to LPG and CNG results in a substantial reduction in the CO emission. CNG also reduced HC and NO_X emissions.

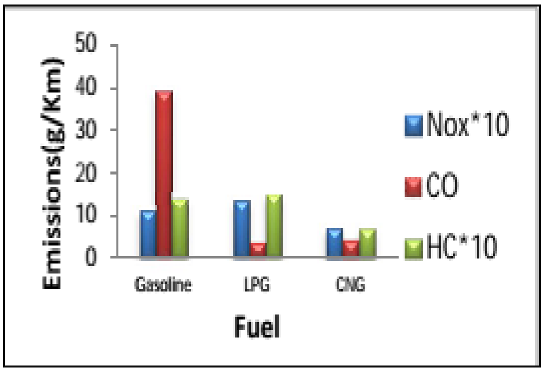

Fig 2 A Summary of Emission with Non-Catalyst Vehicle

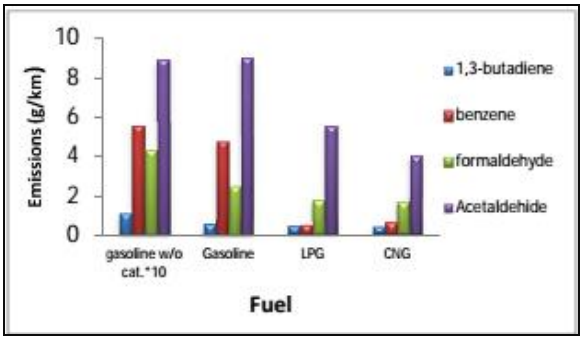

Fig-3 Unregulated emission components different fuel

Table 2 Passenger Car And Heavy Duty Engine

Vehicle type	NOx	NMHC	CO
Passenger car	0.2	0.15	1
Heavy-duty	2.8	0.5	23.2

Table 3 Comparison Of Emissions And Fuel Consumption

Sr. No	Emissions and fuel consumption	Gasoline	LPG
1	CO (g/km)	0.87	0.72
2	HC (g/km)	0.14	0.12
3	NOx (g/km)	0.12	0.16
4	Fuel consumption (l/100km)	8.7	11.3
5	Energy consumption(MJ/km)	2.8	2.7

Modern spark-ignition LPG-fueled engines equipped with a threeway catalyst can easily meet (Euro 2 and 3) stringent heavy-duty emission standards. Lean burn engines in combination with an oxidation catalyst can also achieve very low emission results (Hutcheson 1995). The very low levels of particulate emissions with both stoichiometric and lean-burning LPG engines continue to be their strongest point, particularly as this is attainable with low NOx emissions. LeeS.etal performed experimental study on performance and emission characteristics of an SI engine operated with DME mixed with LPG. The results they obtained showed that knocking was significantly increased with DME due to the high Cetane number of DME. The output engine power of using 10% DME was comparable to that of pure LPG. Exhaust emissions such as HC and NOx were slightly increased when utilizing blended fuel at low engine speeds. Using blended fuel, however, the engine power output was decreased and break specific fuel consumption (BSFC) was extremely deteriorated because the energy content of DME is much lower than that of LPG.

IANGV Emission Report shown that unregulated emissions like (1,3-butadiene,benzene,formaldehyde and methanol of all the alternative fuel) of LPG give vehicles are generally less than formaldehyde levels for gasoline fuels. Graph shows Three-way catalyst technology is efficient in removing not only regulated emission components but also harmful unregulated components. On gasoline, the TWC reduces 1,3-butadiene, benzene and formaldehyde emissions by a factor of more than 10. For these three components, LPG and CNG give lower emissions than gasoline.TNO data on acetaldehyde emissions from non-catalyst vehicle Switching from gasoline to gaseous fuels reduces PAH emissions by a factor of 10. However, one could estimate that the total toxic effects going from gasoline to natural gas in non-catalyst vehicles will be reduced substantially. In all cases studied, LPG energy economy was lower than EPA certification fuel economy data for the pre-conversion gasoline vehicle (i.e. conversion appears to have reduced efficiency on gasoline). All the vehicles tested by EPA also yielded large decrease in acceleration performance, measured by 5-60 mph and 30-60 mph. Finally, each of these DF vehicles had a lower range on LPG than on gasoline, typically at least at a 50 percent reduction. Efficiency, performance and range characteristics can be improved with dedicated and optimized LPG vehicles. Using accepted relationship between weight, acceleration and fuel economy, it was estimated that a LPG with range and power equivalent to the gasoline model would be less efficient (25%). This tradeoff between efficiency, performance and range is the reason why many experts believe LPG and CNG is better suited for centralized urban fleet applications than for general public use. engine was not high compared to the value of diesel engine. The charge stratification in the combustion chamber permits extremely lean combustion that increases the thermal efficiency but gives the penalty of high NOx. Noise, produced by the combustion process cause immediate annoyance and physiological change. Combustion noise occurs in two forms, direct and indirect. Direct noise is generated in and radiated from a region.

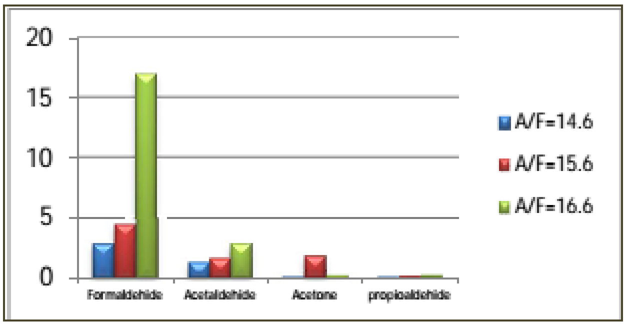

Fig 4 Concentration (ppmv) of aldehydes in exhaust gases of LPG fuelled engine.

Figure 4 shown the concentration (ppmv) of aldehydes in exhaust gases of LPG fuelled engine at rich,stoichiometric and lean Air/fuel ratio.*From the Study done by ETSAP*LPG has a relatively high energy content per unit of mass, but its energy content per unit volume is low. Thus, LPG tanks have more space and weight than petrol or diesel fuel tanks, but the range of LPG vehicles is equivalent to that of petrol vehicles. Bi-fuel LPG car tests show around a 15% reduction in greenhouse gas emissions (per unit of distance) compared to petrol operation. The best quality LPG bi-fuel engines produce fewer NOx emissions and virtually zero particulate emissions if compared to petrol. Fuel Options for Controlling Emissions. Both Stochiometric and lean-burn LPG engines have been developed with good results. Nearly all

LPG vehicles currently in operation are aftermarket retrofits of existing gasoline vehicles, mostly using mechanical (as opposed to electronic) conversion systems.

VII. CONCLUSION

Based on the reviewed paper for the emissions and performance, its concluded that the LPG represents a good fuel alternative for gasoline and therefore must be taken into consideration in the future for transport purpose.Apart from the fuel storage and delivery mechanism, LPG engines similar to petrol engines, and deliver nearly similar performance and good in combustion characteristics than Gasoline.In the short term, LPG as a alternative fuels reviewed could displace 10 per cent of current usage of oil, or bring significant reductions in CO, CO2 emissions and help to reduce harmful greenhouse gas emissions. In the next five to ten years, LPG will be more widely available and gaining market share across vehicle ranges.

VIII. LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS

λ=relative air-fuel ratio

ABBREVIATIONS AND CODES

CVCC- Constant Volume Combustion Chamber

CNG -Compressed Natural Gas

DF - Duel Fuel

DI - Direct Injection

DME - Di-Methyl Ether

ECE - Economic Commission for Europe/ECE test method

EGR - Exhaust Gas Recirculation

EPA - Environmental Protection Agency

EUDC - Extra Urban Driving Cycle

EURO - European Union test method/limit value

ETSAP -Energy Technology System Analysis Programme

GDI - Gasoline Direct Injection

HD -Heavy -Duty

IANGV - International Association for Natural Gas Vehicles

LPG - Liquefied Petroleum Gas

LPLi - Liquefied Petroleum Liquid injection

NMHC - Non-Methane Hydrocarbons

PAH - Polyaromatic Hydrocarbons

TNO -TNO Road-Vehicles Research Institute (Holland)

TWC - Three-Way Catalyst

VE - Volumetric efficiency

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