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Performance and Emission Characteristics of LPG-Fuelled Variable Compression Ratio SI Engine

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Abstract

The growing concern about the fast depletion of petroleum-based fuels and the environmental pollution caused by their combustion has been a compelling incentive to many researchers to find ways to use environmentally friendly and renewable sources of energy. Research and experiments on liquefied petroleum gas (LPG) have demonstrated that this fuel is suitable as an alternative to conventional fuel. Its performance and efficiency parameters are better than the conventional fuel and it can run cleaner at attractive prices and in larger operating range. Among the alternatives found to be superior to the present gasoline is natural gas, hydrogen (H_2), and LPG (i.e. liquefied petroleum gas in the form of either propane, C_3H_8; butane, C_4H_{10}; or a mixture of both). In the present paper, LPG in the form of propane as a fuel has been considered. The present paper evaluates the performance and emission characteristics of a single cylinder, 4-stroke, air-cooled, variable compression ratio spark ignition engine when fuelled with LPG at different compression ratios. The results obtained show that the engine running on an LPG fuel system delivered a substantial improvement in power and torque in a high-load condition. Conversion of the engine using LPG as fuel showed an average reduction of CO and HC exhaust gas emissions in comparison to the original fuel.

Key words: Variable compression ratio engine, LPG, Performance, Emissions, Spark Ignition.

Introduction

Oil reserve all over the world is depleting at an alarming rate. In addition, the deteriorating quality of air we breathe is becoming another great public concern. Emissions of sulfur dioxide, hydrocarbons, carbon monoxide, nitrogen oxides, lead, etc. have stimulated scientists to find ways to reduce these emissions because of their impact on human health and ecological imbalance. These factors along with the oil crisis in the 1970s have led scientists and researchers to search for clean and environmentally friendly alternatives to the conventional fuels used to power internal combustion engines. Various alternative fuels suited for spark ignition (SI) engines can be classified as synthetic gasoline, alcohols, and gaseous fuels according to the studies conducted by Thring (1983) and Prausnitz et al., (1987). Gaseous fuels in general are promising alternative fuels due to their low cost, high octane number, high calorific values, and lower polluting exhaust emissions (Badr et al., 1989; Richard Stone, 1989; Beer, 2002). During the last decade, gaseous fuels such as liquefied natural gas (LNG) and liquefied petroleum gas (LPG) have been widely used in commercial vehicles, and promising results have been obtained in terms of the fuel economy and exhaust emissions. These results have also been confirmed by different published works of Yamin (2002) and Johnson (2003). Existing literatures of Bayraktar (2003), Dagaut et al., (2003), and Selim (2004) on the use of gaseous fuels as engine fuel have obtained for a limited number of specific engines running at specific conditions. Moreover, early papers have focused on only one or a few topics such as engine combustion, performance, or exhaust emissions. For these reasons, in the present study, detailed experimental investigations of a LPG fuelled SI engine for a wide range of operating conditions and at different compression ratios have been carried out and compared with the conventional fuel (e.g. gasoline).

The basic criteria for selecting any alternative is that the fuel has to be in abundant supply or, preferably, derived from renewable sources, it should have high specific energy content, easy transportation and storage, minimum environmental pollution and resource depletion, and lastly, it should have good safety and handling properties. It is well known that with propane, engines tend to operate at leaner mixtures, making the engine operation more economical. The characteristic properties of LPG (propane) are compared with gasoline in Table 1. In the present paper, the experimental and emission results obtained for gasoline and propane are compared and conclusions and recommendations are given.

Experimental Setup

This internal combustion engine was designed and developed to acquire pressure data from pressure transducer and process the same at a faster rate, and provision was made to conduct the experiment for different compression ratios and different fuels. The engine test rig consists of an AC generator for power measurements. There is a provision to obtain cylinder pressure-crank angle, and a cylinder pressure volume diagram required for determination of indicated power of the engine. Provision was also made for the measurement of airflow, fuel flow, back pressure, cooling water flow, temperature, and load. The test rig enables the study of engine performance involving indicated power, brake power, thermal efficiency, volumetric efficiency, fuel consumption, and air-fuel ratio. The software developed is fully configurable. This rig is in line with the present day trends in which the tests are interfaced with computers for speedy and accurate experimentation and data analysis. In this test rig, various measurements and provisions were carried out to calculate the performances. The experimental test rig is shown in Figure 1 with required specifications, which are given in Table 2.

Results and Discussions

The performance is conducted on a variable compression ratio engine using petrol and LPG at constant speeds (2500 and 2800 rpm), with varying loads, and at varying compression ratios like 7:1 and 10:1. Various parameters such as brake thermal efficiency, brake specific fuel consumption, volumetric efficiency, and CO and HC emissions are calculated. The characteristic curves were drawn and the detailed results are discussed in this paper. Some of the experimental findings are as follows:

From Figures 2 and 3, it is found that, as the brake power increases, there is considerable amount of increase in brake thermal efficiency. The maximum brake thermal efficiency with petrol is 34.02% at 2800 rpm (CR 7:1) ; 39.06% at 2800 rpm (CR 10:1) ; 31.89% at 2500 rpm (CR 7:1) ; 35.5% at 2500 rpm CR 10:1, and maximum brake thermal efficiency with LPG is 27.8% at 2800 rpm (CR 7:1); 30.2% at 2800 rpm (CR 10:1); 16.98% at 2500 rpm (CR 7:1); and 28.2% at 2500 rpm (CR 10:1).

Table 1. A comparison of LPG and gasoline properties.

Characteristics	Propane	Gasoline
Chemical formula	C_3H_8	C_8H_{18}
Boiling point (°C)	-44	30-225
Molecular weight (kg/Kmol)	44.1	114.2
Density at 15 °C kg/l	0.507	0.705
Research Octane Number	100	96-98
Stoichiometric air fuel ratio (kg/kg)	15.6	14.7
Flame speed (m/s)	48	52-58
Upper Flammability limits in air (% vol)	74.5	7.6
Lower Flammability limits in air (% vol)	4.1	1.3
Lower calorific value (kJ/kg)	46.365	42.1

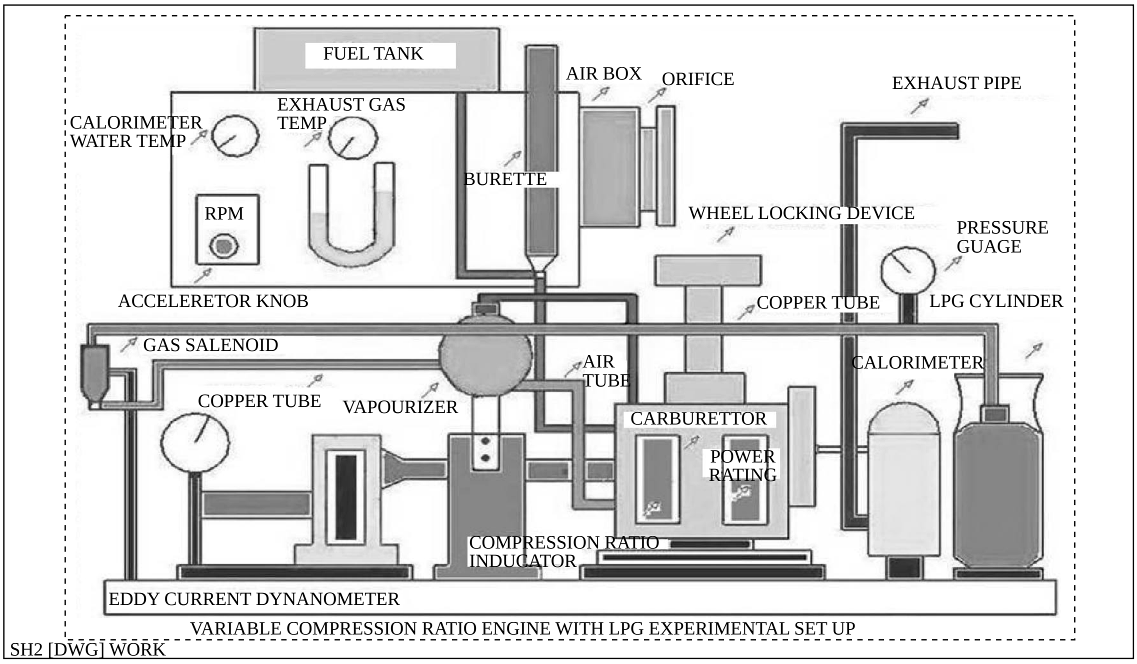

Figure 1. Experimental test rig.

Table 2. Specifications of the engine.

Type	4-stroke, single cylinder diesel engine (water-cooled), compression ignition.
Make	Kirloskar AV -1
Rate power	3.7 kW, 1500 RPM
Bore &Stroke	85 mm X 110 mm
Compression Ratio	6 to 25:1
Cylinder Capacity	624.19 cc
Orifice Diameter	15 mm

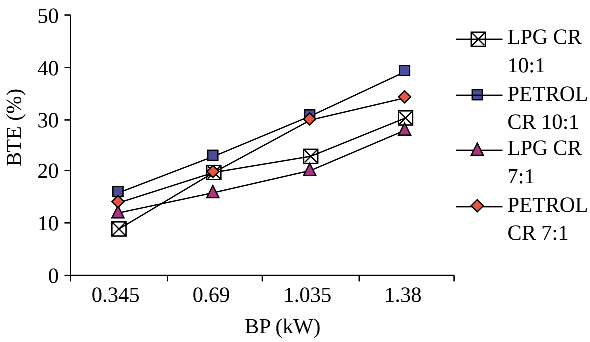

Figure 2. BP vs. BTE @ 2800 rpm.

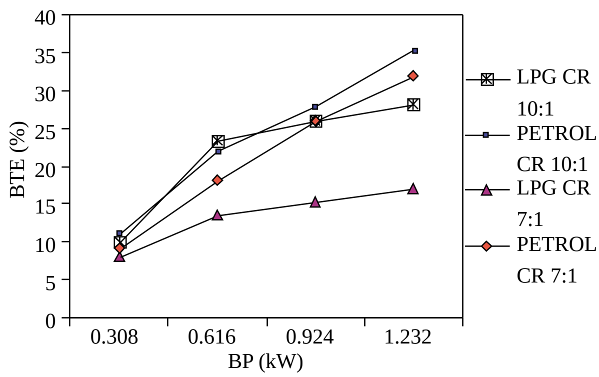

Figure 3. BP vs. BTE @ 2500 rpm.

Figures 4 and 5 indicate that the brake specific fuel consumption decreases as the load on the engine increases. The minimum BSFC with LPG is 0.24 kg/kw hr at 2800 rpm (CR 7:1); 0.267 kg/kw hr at 2800 rpm (CR 10:1); 0.2 kg/kw hr at 2500 rpm (CR 7:1); 0.23 kg/kw hr at 2500 rpm (CR 10:1), and minimum brake specific fuel consumption with petrol is 0.225 kg/kw hr at 2800 rpm (CR 7:1); 0.25 kg/kw hr at 2800 rpm (CR 10:1); 0.19 kg/kw hr at 2500 rpm (CR 7:1); 0.21 kg/kw hr at 2500 rpm (CR 10:1). As can be clearly seen from these figures, LPG increases the specific fuel consumption of the engine in comparison with petrol.

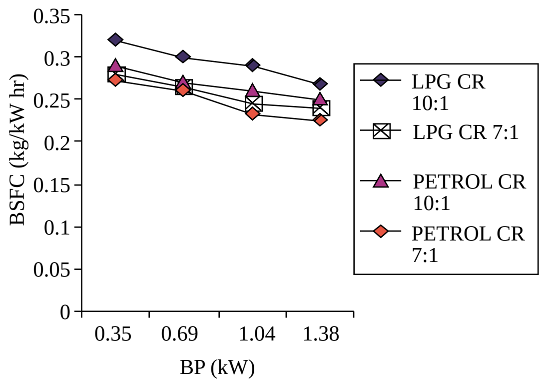

Figure 4. BP vs. BSCF @ 2800 rpm.

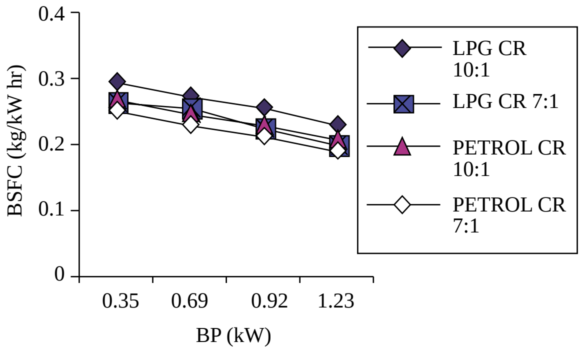

Figure 5. BP vs. BSCF @ 2500 rpm.

Figures 6 and 7 show the variation of volumetric efficiency with brake power at engine speeds of 2800 rpm and 2500 rpm at compression ratios of 7:1 and 10:1. The maximum value obtained for volumetric efficiency with LPG for an engine speed corresponding to 2800 rpm at compression ratios of 7:1 and 10:1 is 58.7% and 62.23 %, respectively. On the other hand, for petrol at the same engine speed of 2800 rpm, the maximum volumetric efficiency is 60.7% and 65.67% at 7:1 and 10:1 compression ratios. The maximum value obtained for volumetric efficiency with LPG as seen from Figure 7 for an engine speed of 2500 rpm at compression ratios of 7:1 and 10:1 is 57.4% and 60.32%, respectively. Whereas, for petrol at the same engine speed of 2500 rpm, the maximum volumetric efficiency is 58.43% and 63.5% at 7:1 and 10:1 compression ratios. It was found that for LPG the volumetric efficiency increases with an increase of compression ratio and speed. In comparison with petrol, LPG has less volumetric efficiency.

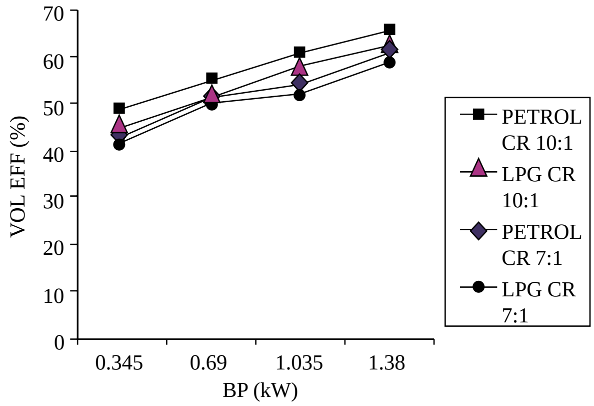

Figure 6. BP vs. VOL EFF @ 2800 rpm.

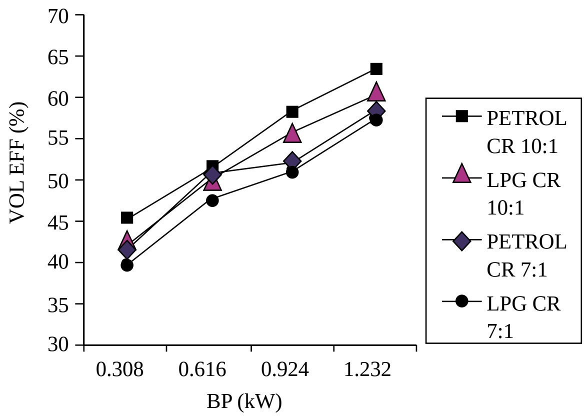

Figure 7. BP vs. VOL EFF @ 2500 rpm.

CO is produced when there is not enough air in the combustion chamber. When the fuel does not burn completely, the carbon in the fuel will convert into CO. It was found that there was a variation trend of CO for the LPG fuel system when it is operated at normal and high operating conditions. As it is seen in Figures 8 and 9, as the compression ratio increases, speed and CO emissions also increase.

The maximum value of CO emissions for LPG are 0.11% at 2800 rpm, CR 10:1; 0.07% at 2800 rpm, CR 7:1; 0.08% at 2500 rpm, CR 10:1; 0.06% at 2500 rpm, CR 7:1 and with petrol, 0.82% at 2800 rpm, CR 10:1; 0.78% at 2800 rpm, CR 7:1; 0.71% at 2500 rpm, CR 10:1; 0.68% at 2500 rpm, CR 7:1. The CO emission increases with incomplete combustion of fuel and it is higher with petrol compared with LPG.

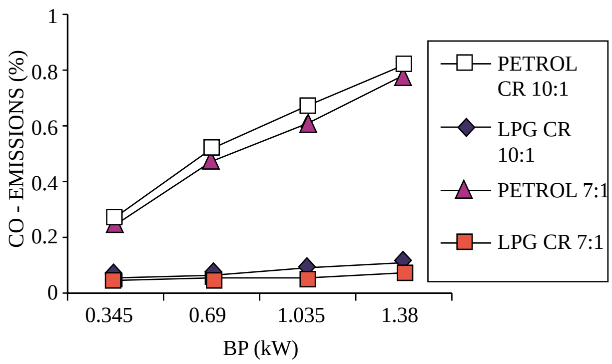

Figure 8. BP vs. CO-EMISSIONS @ 2800 rpm.

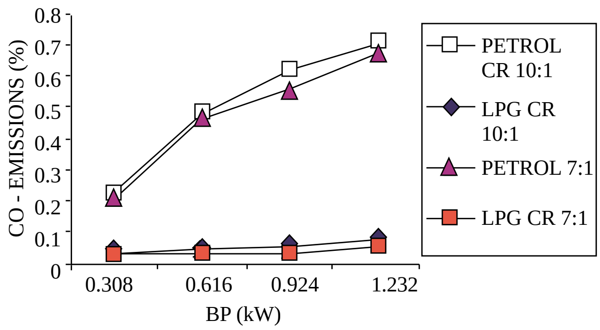

Figure 9. BP vs. CO-EMISSIONS @ 2500 rpm.

From Figures 10 and 11, it is found that as the compression ratio increases, speed and HC emission increase. Maximum HC emission for LPG is 273 ppm at 2800 rpm, CR 10:1; 261 ppm at 2800 rpm, CR 7:1; 243 ppm at 2500 rpm, CR 10:1; 237 ppm at 2500 rpm, CR 7:1 and with petrol, 1936 ppm at 2800 rpm, CR 10:1; 1856 ppm at 2800 rpm, CR 7:1; 1905 ppm at 2500 rpm, CR 10:1; 1801 ppm at 2500 rpm, CR 7:1. CO emission increases with incomplete combustion of fuel and it is higher for petrol when compared with LPG.

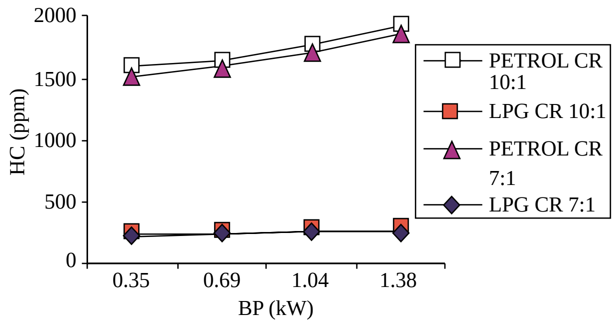

Figure 10. BP vs. CO-EMISSIONS @ 2800 rpm.

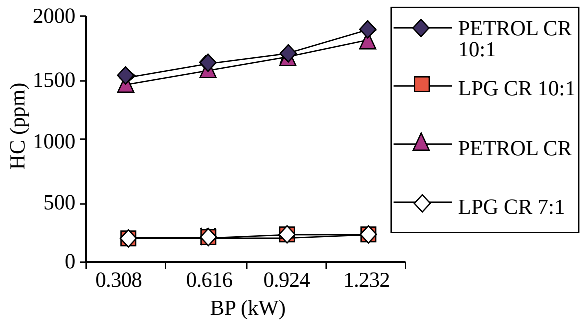

Figure 11. BP vs. CO-EMISSIONS @ 2500 rpm.

Conclusions

As compression ratio increases, brake thermal efficiency increases. LPG has a higher octane rating and hence the engine can run effectively at relatively high compression ratios without knock. LPG increases the specific fuel consumption of the engine. LPG reduces the engine volumetric efficiency, and thus, engine effective power. Furthermore, the decrease in volumetric efficiency also reduces the engine effective efficiency and consequently increases specific fuel consumption.

The CO and HC emissions increase as the compression ratio, speed, and load increase. In the case of using LPG in SI engines, the burning rate of fuel is increased, and thus, the combustion duration is decreased. Therefore, the cylinder pressures and temperatures predicted for LPG are higher compared to gasoline. This may cause some damages on engine structural elements. LPG is free of lead and has very low sulphur content. Combustion of gaseous fuels like LPG occurs in a nearly uniform fuel air mixture leading to a reduction in incomplete combustion deposits such as soot on the walls of combustion chamber.

Recommendations

In the present study, LPG has been considered to consist of only propane. It is evident that if the other components included in LPG were taken into account, more realistic results could be obtained. As it is known, LPG has a high octane number. Thus, it may lead to operating conditions with higher compression ratios, such as 11:1 and 2:1, and consequently, the engine efficiency and fuel economy would be better compared to those discussed in this paper. Although some negative effects of LPG on engine performance, fuel economy and engine structural elements have been determined, it may be suggested as an alternative fuel for SI engines due to ecological reasons. In this case, the engine cooling performance should be improved and structural elements such as piston, valves, and cylinder must be produced from materials that have better resistance to high pressures and temperatures. Nevertheless, LPG systems that inject LPG into the inlet port in liquid state rather than as a gas improve the volumetric efficiency. There is also scope for direct injection of liquid LPG into the cylinder, in the manner of GDI engines, and this would improve the performance of LPG fuelled vehicles further.

Summary

In summary, LPG has negative effects on engine performance, fuel economy, and engine structural elements when it is used at the same fuel/air equivalence ratios as gasoline, however, it has positive effects on obnoxious exhaust emissions such as CO and HC.

Nomenclature

SI	spark ignition
BTE	brake thermal efficiency
BP	brake power
CR	compression ratio
BSFC	brake specific fuel consumption
VOL EFF	volumetric efficiency
CO	carbon monoxide
HC	hydrocarbons

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