Parametric Study of Engine Operation on Petrol and Liquefied Petroleum Gas

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Abstract

This study expounds on useful parameters for engine tests in the case of a single-cylinder, four-stroke, spark-ignition engine. Deviations from desired operation standards and the resulting losses provide reasons for the study and analysis of those parameters. Knowledge obtained from such studies is useful in planning for improvements and better utilisation of fuels – petrol and liquefied petroleum gas, (LPG) in this case.

The set-up of the experiment consisted of an engine system, coupled to a hydraulic dynamometer, and connected to a versatile data acquisition system, (VDAS). LPG operation was achieved through an improvised system to introduce it to the test engine. Gaseous fuels are considered as less polluting and are regarded to as clean fuels. The engine was run at different speeds and varying loads. Performance parameters namely, torque, air mass flow rate, power, exhaust gas temperature, brake mean effective pressure and volumetric efficiency were recorded.

Tabulation and graphical representation of parametric values was done. At speeds below 2400 rpm, petrol exhibited superior performance characteristics; while beyond this speed, LPG's performance characteristics proved better.

Key words: LPG, Petrol, SI Engine, VDAS

Introduction

Ideally, engines should operate at maximum thermal and volumetric efficiencies, with minimum mass fuel consumption, and with reduced specific fuel consumption while at the same time producing greater power output and lesser emissions.

In reality, these ideals are not always met because of several contributing factors like fuel quality, adverse ambient operating conditions e.g. extremely cold climatic conditions, engine structure, frictional losses, heat losses due to cooling etc.

As a consequence, the engine operation may exhibit unfavourable characteristics such as: more fuel consumption, incomplete combustion, production of less brake power and hydrocarbon, (HC) and NO_X concentrations beyond legal emission limits. This poses a greater threat to the environment and also leads to higher operation costs.

To counter these obstacles, and to reduce effects of wear and tear thus increasing engine life; research has been carried out extensively, to look into the possibility of using alternative fuels in running internal combustion engines. One such fuel is Liquefied Petroleum Gas (LPG) which can be used to operate a petrol-fuelled Spark Ignition (SI) engine.

This study analysed data from a spark ignition engine under both LPG and petrol operations and a comparison was made. Four stroke, single cylinder Otto engines can be used widely in farms in rural parts of Kenya to carry out useful tasks such as running reciprocating pumps for irrigation and water storage in tanks positioned at any practical height above the ground. These engines may also be used to run the rotor of a generator and provide electricity for lighting.

This project seeks to improve on the utilization of LPG which is mainly used for cooking locally and globally. As well as providing users of LPG with an understanding of the fuel consumption behaviour of the engine at various loading conditions, this study will also give an insight on other parameters of the LPG-fuelled engine e.g. efficiency and the power output.

Since LPG is easily available and at an affordable cost, the analysis also targets to cut on the fuel costs incurred in running these engines. The findings of this study should aid in maintenance hence increase the engine life in both petrol and LPG fuel operations. In summary, the users of petrol and LPG fuels should be able to make better informed decisions.

Finally, this study provides a foundation upon which improvements can be made on petrol and LPG engine operations. If found that LPG performs better than Petrol, LPG usage can be promoted by policy makers in the country as its properties also point to reduced emission.

Set-Up

The major components of the setup were:
- Engine
- Hydraulic dynamometer
- VDAS software
- VDAS display module
- Fuel tank
- LPG Cylinder

1.1 Engine

The base engine for this experiment was TD201 Four-Stroke Petrol Engine, a small modern engine, specifically adopted for use with TecQuipment's TD200 Small Engine Test set.

Table 0.1 - Technical details of the engine

Item	**Specifications**
Dimensions (when fitted to Base Plate)	Width 400 mm, height 400 mm, depth 300 mm
Net weight (with base plate)	20 kg
Fuel type	Unleaded Petrol (Gasoline) LPG
Fuel tank	Red-painted steel with vents and a filler cap
Exhaust outlet	Normally 1"BSP
Ignition system	Electric
Absolute Maximum Power	4.4 kw (6hp) at 4000 rpm.
Bore	67 mm
Stroke/Crank Radius	49 mm/24.5 mm
Connecting Rod length	85 mm
Engine Capacity	172cc or 172 cm^3
Compression Ratio	8.5:1
Oil type*	SAE20, SAE30 or Multigrade 10W-30
Oil Capacity	0.65 litres
LPG	2.74 kPa
Tubes	Flexible plastic able to withstand 30 bar
Gas cylinder	4.5 kg, steel vessel , pressure 30 bar

1.2 Hydraulic dynamometer

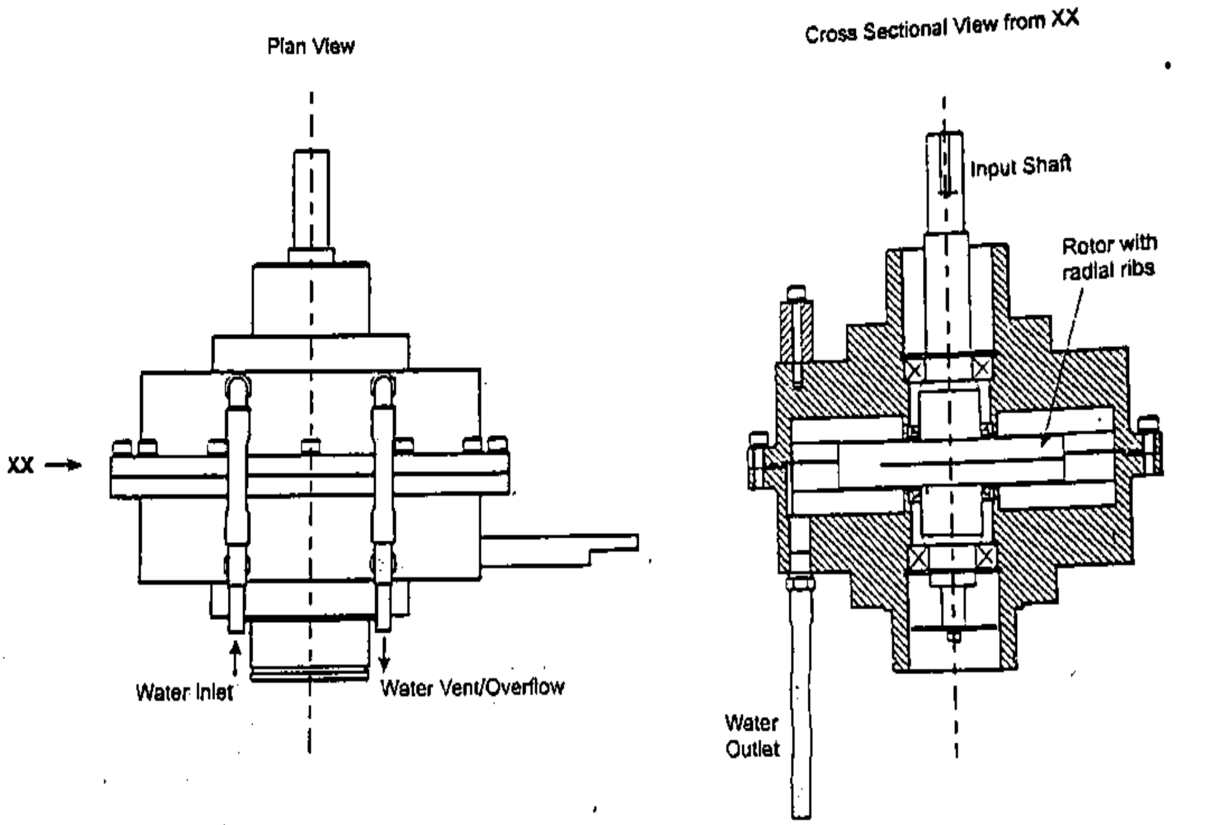

Figure 0.1 - Hydraulic dynamometer

A trunnion-mounted hydraulic dynamometer was fixed on the test bed. Load applied depended on water flow rate and the level of water in the dynamometer casing. The flow rate was controlled by an accurate needle valve.

Torque was measured by means of an electric load cell on the side of the Dynamometer.

A proximity sensor measured the dynamometer's speed of rotation.

When the rotor was turned by the engine, the ribs on the casing and rotor were caused to churn. This gave a resistive torque which was measured by the load cell. The amount of resistance varied with changes in water flow rate and the height of water in the casing.

Control of dynamometer load was indirect by means of a needle valve at the water inlet. Load control was an open loop system.

1.3 Versatile Data Acquisition System (VDAS)

The TecQuipment VDAS (Versatile Data Acquisition System) is an excellent software for use with many TecQuipment's products.

The software did the following:

- Display real time data on an analogue meter or in a digital format.
- Log data for printing or for viewing later.
- Export data as HTML format for use by another computer software.
- Perform real-time calculations on data to generate user-defined data.
- Use data to create and print data charts and data tables.
- Record data automatically or with some manual input.

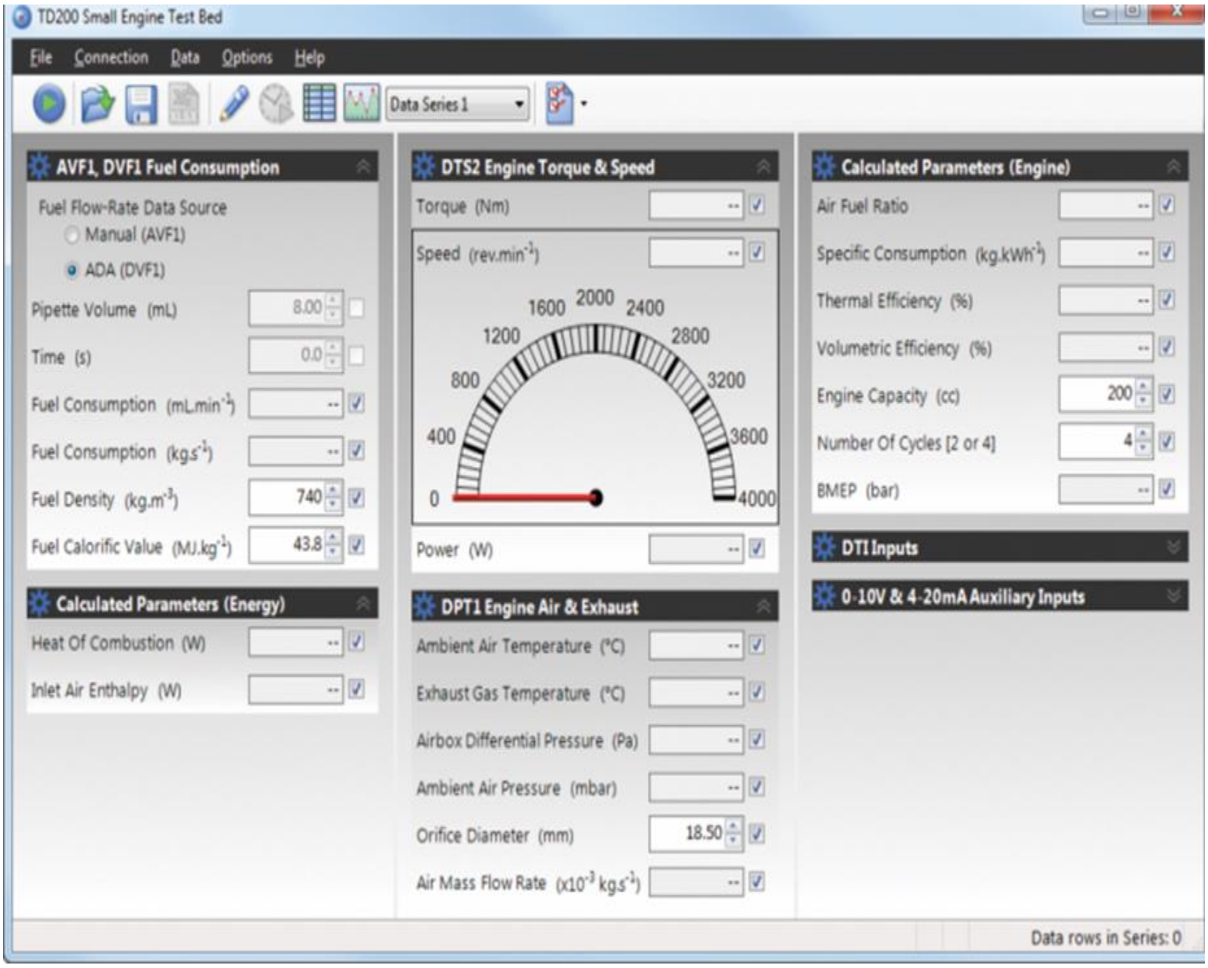

Figure 0.2 - VDAS software display

1.4 LPG injection system

LPG was stored under high pressure: as a liquid in a steel cylinder. Since LPG boils at a temperature of -42°C and a pressure of zero, it drew heat from the steel walls of the gas cylinder. The walls of the gas cylinder drew heat from ambient air.

LPG boiled and turned to gas when some pressure was released by turning on gas consumption. This process is called vaporization. It caused the gas cylinder temperature to reduce.

Once the LPG had vaporized and released via the control valve on the cylinder outlet, it flowed along a tube strong enough to withstand high pressure (30 bar) and into a flow-meter. The flow-meter was held perpendicular to the horizontal. It had a light ball which was raised through a certain height depending on the amount of gas flowing across it.

The position of the ball indicated gas flow rate from the LPG cylinder. Flow rate variation at the cylinder outlet had a direct effect on engine parameters, the rate of LPG consumption included. From the flow-meter, gas flowed into the carburettor where it mixed with air from the air box at the venturi throat, then, flowed into the manifold before finally being injected into the combustion chamber.

Methodology

1.5 Data collection for petrol

The TecQuipment VDAS Software was set to run after the engine was started. At the interface, a connection to the panel was created to enable data input to the monitor. This had to be repeated for each successive data series to be recorded.

The data could be captured manually or automatically by a timed data acquisition system within the software.

For automatic timed data acquisition, the time interval between data capturing as well as the number of readings desired were specified. Data acquisition would then be prompted by clicking "start" and this would stop after the final reading had been taken.

The downside of this method was that the software took no note of inconsistencies that arose during engine operation, and therefore, values recorded this way at times proved inconsistent.

For the manual data acquisition system, the user was able to record data values at no specified time interval. The manual system was preferred over automatic timed data acquisition as it allowed engine behaviour to be monitored and data values would then be captured when the engine was running smoothly and in a stable manner.

Upon starting the engine, the choke and the throttle were held at fixed positions. The engine speed was varied by allowing different amounts of load to pass through the inlet valve and reach the hydraulic dynamometer.

Readings for engine speed were taken by directly observing the values on the VDAS panel or by sticking a reflective marker on the coupling between the engine shaft and the dynamometer shaft and using a photo tachometer to measure the speed. The tachometer readings and the VDAS panel readings showed negligible deviations from each other.

At a specific load, three sets of data series were captured and the mean value of each recorded parameter was calculated. An allowance of +50 or -50 to the rpm readings was permitted at every speed and load conditions.

Fuel consumption was displayed on the frame-mounted VDAS panel as the engine was fitted with sensors that monitor the same. However, on the frame was also a pipette that allowed fuel consumption to be monitored manually by observing and timing using a stopwatch, the period it took to empty 8 ml, 16 ml or 24 ml of petrol from the pipette. The amount emptied would then be divided by the time period between two successive fuel refills of the pipette to find the rate of consumption.

Exhaust gas temperature was measured by an exhaust thermocouple and was displayed on the VDAS panel. However, for ambient temperature: both manual measurements using a mercury-in-glass thermometer, as well as the automatic method of using a thermocouple; were used interchangeably as they showed negligible deviation from each other.

The engine had a modified cylinder head and crank to allow usage with a cylinder head pressure transducer and a crank angle encoder. The pressure transducer gave values for in-cylinder pressure while the crank angle analyser was connected to the Engine Cycle Analyser (ECA100 software) to display crank position during each cycle.

Also, air pressure differential was displayed on the frame-mounted panel but manual recording of this was also possible by using a manometer linked to the airbox by a pipe on one end while the other end was open to atmospheric pressure. The resulting head was in inches of water.

From the formula;

$$\Delta p = H_w \, . \, \rho_w \, . \, g$$

Where; Δp – *Pressure differential*
H_w – *Head in metres (1 inch = 0.0254m)*
ρ_w – *Density of water in* $kg.m^{-3}$
g – *Gravity constant*

the pressure differential was calculated and was found to be similar to that displayed on the VDAS panel.

Parameters such as torque could be taken directly from the readings whereas other parameters like air mass flow rate were derived from the readings taken, through calculations. Manual calculations yielded results similar to that of the software e.g. for air mass flow rate, which was calculated from differential pressure, Δp, the findings are shown below.

Applying the formula:

$$\dot{m}_a = C_d \frac{\pi d^2}{4} \sqrt{\frac{2 p_A \Delta p}{R T_A}}$$

and the operating conditions were such that:

$$C_d = 0.6$$
$$d = 0.0185m$$
$$p_A = 832 \text{ mbar}$$
$$R = 287 \ J.kg^{-1}K$$
$$T_A = 299.5 \ K$$

At 2145 rpm

$$\dot{m}_a = 0.6 \times \frac{\pi \times 0.0185 \times 0.0185}{4} \sqrt{\frac{2 \times 83200 \times 68}{287 \times 299.5}} = 1.85 \times 10^{-3}\ kg.s^{-1}$$

At 2450 rpm

$$\dot{m}_a = 0.6 \times \frac{\pi \times 0.0185 \times 0.0185}{4} \sqrt{\frac{2 \times 83200 \times 90}{287 \times 299.5}} = 2.13 \times 10^{-3}\ kg.s^{-1}$$

At 2761 rpm

$$\dot{m}_a = 0.6 \times \frac{\pi \times 0.0185 \times 0.0185}{4} \sqrt{\frac{2 \times 83200 \times 115}{287 \times 299.5}} = 2.41 \times 10^{-3}\ kg.s^{-1}$$

At 3032 rpm

$$\dot{m}_a = 0.6 \times \frac{\pi \times 0.0185 \times 0.0185}{4} \sqrt{\frac{2 \times 83200 \times 139}{287 \times 299.5}} = 2.65 \times 10^{-3}\ kg.s^{-1}$$

At 3327 rpm

$$\dot{m}_a = 0.6 \times \frac{\pi \times 0.0185 \times 0.0185}{4} \sqrt{\frac{2 \times 83200 \times 165}{287 \times 299.5}} = 2.88 \times 10^{-3}\ kg.s^{-1}$$

At 3627 rpm

$$\dot{m}_a = 0.6 \times \frac{\pi \times 0.0185 \times 0.0185}{4} \sqrt{\frac{2 \times 83200 \times 179}{287 \times 299.5}} = 3.00 \times 10^{-3}\ kg.s^{-1}$$

Table 0.1 - Air mass flow rate indicated by the VDAS software

Speed (rpm)	**Δp (Pa)**	**$\dot{m}_a$ ($\times 10^{-3}$ kg.s^{-1})**
2145	-68	1.85
2450	-90	2.13
2761	-115	2.41
3032	-139	2.65
3327	-165	2.88
3627	-179	3.00

The air mass flow rate obtained from manual calculations tallied with that indicated by the VDAS Software.

1.6 Data collection for LPG

Data collection for LPG was similar to that of petrol in the sense that the choke and throttle were maintained at a fixed position. Engine speed variation was possible in two different ways. Firstly, by adjusting load at the dynamometer where more resistive torque resulted in reduced engine speed and vice versa: and secondly, by varying the amount of gas flowing through the LPG cylinder outlet, through the flow meter and into the carburettor.

Engine speed readings from the VDAS panel and tachometer were used interchangeably as they differed only slightly.

Connections between the engine, the panel and the computer were alike to that used in recording data for petrol. The steps taken in capturing data with the computer were repeated with the option of using automatic timed data acquisition or going the manual way. The manual method was preferred.

Again, three sets of data series were captured at each speed and the average value calculated for each parameter at that speed.

LPG flowing from the storage cylinder was measured in Standard Cubic Feet per Hour (SFCH) by an air flow meter. An assumption was made: that one hundred percent of the gas flowing across the air flow meter was used up in the engine combustion process.

Exhaust gas temperature was measured by an exhaust thermocouple while ambient temperature was measured by means of a thermocouple or manually by a mercury-in-glass thermometer.

The in-cylinder pressure and crank position were obtained from the cylinder head pressure transducer and crank angle encoder respectively: as was the case with petrol.

Air mass flow rate readings were taken from the VDAS computer program, as well as being calculated manually, from air pressure differential readings. The procedure followed here was similar to that used in petrol analysis.

Torque and power readings were taken directly from the computer.

A comparison was made between the values of air mass flow rate recorded by the computer and that found by manual calculation.

Applying the formula:

$$\dot{m}_a = C_d \frac{\pi d^2}{4} \sqrt{\frac{2 p_A \Delta p}{R T_A}}$$

and the operating conditions were such that:

$$C_d = 0.6$$
$$d = 0.0185m$$
$$p_A = 833\ mbar$$
$$R = 287\ J.kg^{-1}K$$
$$T_A = 300.1\ K$$

At 2106 rpm

$$\dot{m}_a = 0.6 \times \frac{\pi \times 0.0185 \times 0.0185}{4} \sqrt{\frac{2 \times 83300 \times 65}{287 \times 300.1}} = 1.81 \times 10^{-3}\ kg.s^{-1}$$

At 2412 rpm

$$\dot{m}_a = 0.6 \times \frac{\pi \times 0.0185 \times 0.0185}{4} \sqrt{\frac{2 \times 83300 \times 74}{287 \times 300.1}} = 1.93 \times 10^{-3}\ kg.s^{-1}$$

At 2712 rpm

$$\dot{m}_a = 0.6 \times \frac{\pi \times 0.0185 \times 0.0185}{4} \sqrt{\frac{2 \times 83300 \times 104}{287 \times 300.1}} = 2.29 \times 10^{-3}\ kg.s^{-1}$$

At 3012 rpm

$$\dot{m}_a = 0.6 \times \frac{\pi \times 0.0185 \times 0.0185}{4} \sqrt{\frac{2 \times 83300 \times 133}{287 \times 300.1}} = 2.59 \times 10^{-3}\ kg.s^{-1}$$

At 3310 rpm

$$\dot{m}_a = 0.6 \times \frac{\pi \times 0.0185 \times 0.0185}{4} \sqrt{\frac{2 \times 83300 \times 149}{287 \times 300.1}} = 2.74 \times 10^{-3}\ kg.s^{-1}$$

At 3607 rpm

$$\dot{m}_a = 0.6 \times \frac{\pi \times 0.0185 \times 0.0185}{4} \sqrt{\frac{2 \times 83300 \times 165}{287 \times 300.1}} = 2.88 \times 10^{-3}\ kg.s^{-1}$$

Table 0.2 - Air mass flow rate indicated by the VDAS software

Speed (rpm)	Δp (Pa)	$\dot{m}_a$ ($\times 10^{-3}$ $kg.s^{-1}$)
2106	-65	1.81
2412	-74	1.93
2712	-104	2.29
3012	-133	2.59
3310	-149	2.74
3607	-165	2.88

Values from the computer and that obtained from manual calculations matched.

Results & Discussion

Experimental results obtained from the tests conducted provided a basis for parametric analysis.

Table 0.1 - Readings for petrol

Speed (rpm)	**Torque** (N.m)	**Power** (W)	**BMEP** (bar	**Volumetric Efficiency** (%)	**Air Mass Flow Rate** ($x10^{-3}$ kg/s)	**Exhaust Gas Temp.** (°C)
2145	7.4	1677	4.67	53.36	1.85	496
2450	7.3	1886	4.62	53.92	2.13	539
2761	6.1	1770	3.84	54.05	2.41	557
3032	6.0	1926	3.81	54.12	2.65	580
3327	4.1	1424	2.66	53.72	2.88	587
3627	3.1	1161	1.92	51.41	3.00	588

Table 0.2 - Readings for LPG

Speed (rpm)	**Torque** (N.m)	**Power** (W)	**BMEP** (bar)	**Volumetric Efficiency** (%)	**Air Mass Flow Rate** ($x10^{-3}$ kg/s)	**Exhaust Gas Temp.** (°C)
2106	6.5	1445	4.09	53.2	1.81	500
2412	7.3	1825	4.54	49.51	1.93	512
2712	7.2	2024	4.49	51.44	2.29	540
3012	7.0	2222	4.43	53.36	2.59	567
3310	6.8	2354	4.27	51.45	2.74	580
3607	6.6	2486	4.11	49.55	2.88	593

The values displayed on the tables above represent the average of three different data series with close to identical values. This was done in order to improve on the accuracy of the results obtained.

The difference in values obtained for petrol and LPG was largely due to dissimilarities in their internal properties as shown in the table below:

Table 0.3 - Properties of petrol and LPG

Properties	**Petrol**	**LPG**
Chemical Structure	C_7H_{17}/C_4 to C_{12}	C_3H_8
Molecular Weight (kg/kmol)	106.2	44
Density (kg.m^{-3})	740	550 (liquid) or 1.898 (gaseous)
Boiling Point (°C)	80 - 437	- 42
Specific Gravity	0.74	0.55 (liquid) or 0.0019 (gaseous)
Research Octane Number (RON)	96	103
Motor Octane Number (MON)	87	94
Flammability Limits (Volume % in air)	1.4 - 7.6	2.2 - 9.5
Flash Point (°C)	- 43	- 104
Auto-ignition Temperature (°C)	246	470
Flame Temperature (°C)	1954	1967
Laminar Flame Speed (m/sec)	0.3	0.38
Lower Heating Value (MJ/kg)	43.44	46.67
High Heating Value (MJ/kg)	46.53	50.15
Latent Heat of Vaporization (kJ/kg)	9.94	14.52
Energy Density (MJ/L)	34.2	26
Stoichiometric Air-Fuel-Ratio (AFR)	14.6	15.5

The values obtained from tests with petrol, were used for reference in calculating the percentage change resulting from modification to LPG. Therefore, all the increase and reductions mentioned in the discussion stand for LPG'S results with respect to that obtained from tests with petrol at the same speed.

1.7 Torque

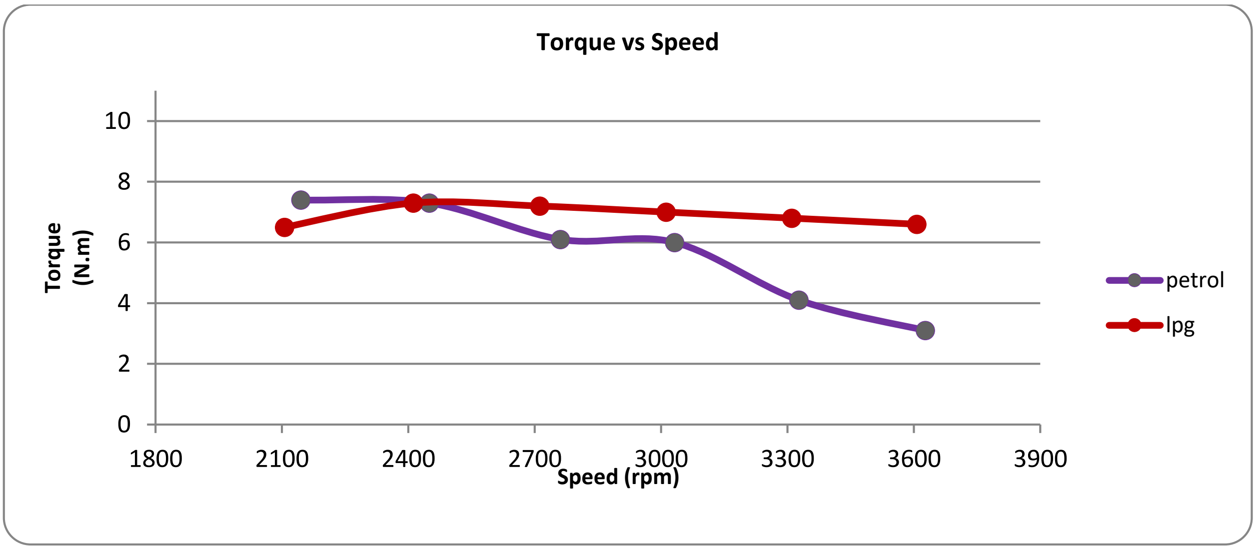

Figure 0.1 - Torque against speed

Table 0.4 - LPG's torque deviation from petrol value

Speed (rpm)	2100	2400	2700	3000	3300	3600
% Change	-12	0	18	17	66	113

LPG generated a higher torque in all the experimental speeds except at 2100 rpm and at 2400 rpm.

At 2100 rpm, torque produced was less by 12%.

At 2400 rpm, the resulting torque was same for both petrol and LPG.

As speed increased to 2700 rpm, to 3000 rpm, to 3300 rpm and to 3600 rpm; torque increased by 18%, 17%, 66% and 113% respectively.

At 2700 rpm and at 3000 rpm, the increase in torque was relatively small as compared to the very rapid increase observed at speeds beyond 3000 rpm.

At 3600 rpm, torque from LPG operation was more than double that produced from running the engine on petrol.

The engine test was carried out with both the choke and the throttle at 100% open positions.

This allowed increased airflow into the carburettor and this paved way for lean operating conditions. Under the lean conditions, LPG had a higher laminar flame speed than petrol.

Because of faster flame propagation, LPG also displayed faster fuel burning rate and shorter combustion durations as compared to petrol. As a consequence, the engine attained higher values for pressure and temperature conditions with LPG as fuel in comparison to those attained with petrol as fuel.

Again, the faster fuel burning rate and the shorter combustion durations prompted the LPG-fuelled engine to increased fuel consumption. Excess enthalpy from the higher LPG consumption further boosted the in-cylinder pressure and the in-cylinder temperature.

When compared to petrol, the higher pressure and higher temperature realised from LPG combustion yielded more power; to carry more load, hence greater torque.

1.8 Air mass flow rate

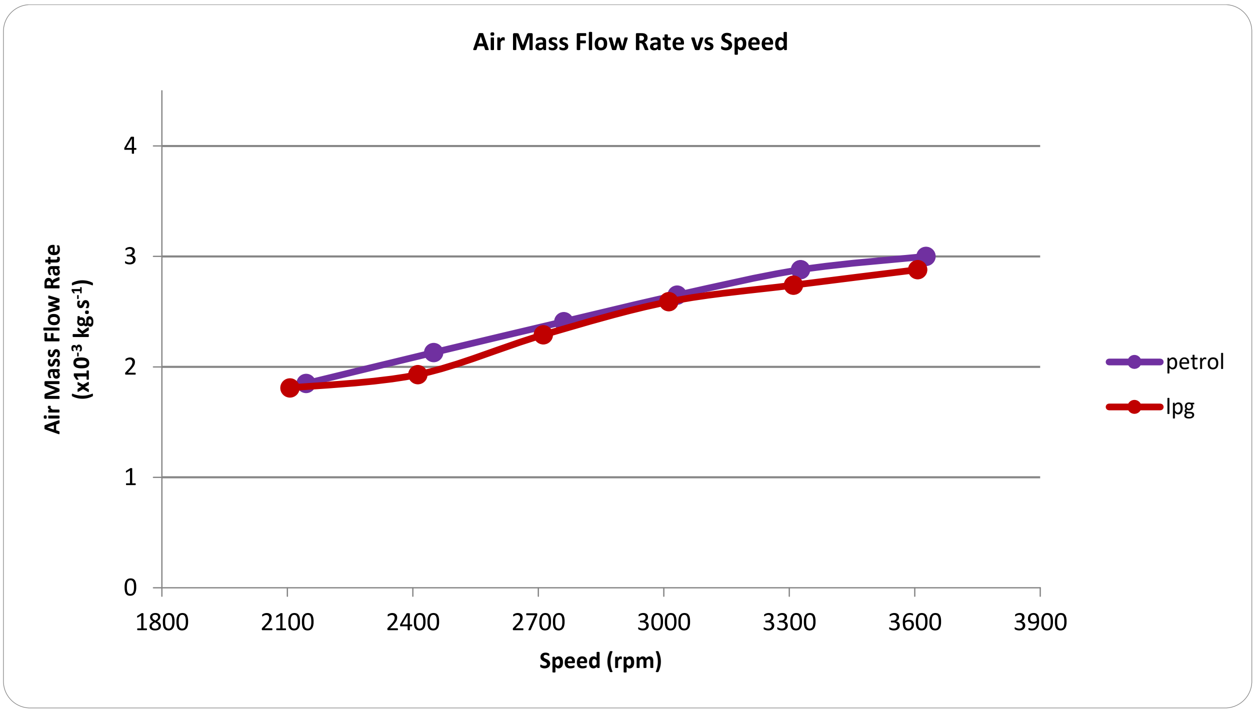

Figure 0.2 - Air mass flow rate against speed

Table 0.5 - LPG's air mass flow rate deviation from petrol value

Speed (rpm)	2100	2400	2700	3000	3300	3600
% Change	-2	-9	-5	-2	-5	-4

LPG had a lower mass flow rate in all the experimental speeds.

At 2400 rpm, the largest decrease in air mass flow rate was observed at 9% reduction.

At 2100 rpm, 2700 rpm, 3000 rpm, 3300 rpm and 3600 rpm, the percentage reduction in air mass flow rate was quite similar.

The reductions observed in LPG's air mass flow rate, were as a result of LPG displacing 15 – 20% greater volume of air as compared to petrol. This meant that a lesser volume of air was introduced into the combustion chamber during the intake stroke for LPG as compared to petrol's intake stroke. Therefore, at similar rpm's, LPG exhibited lesser air volume flow rate into the engine.

Considering that air density was constant during both engine operations and that;

$$\textit{air mass flow rate} = \textit{air density} \times \textit{air volume flow rate}$$

then LPG resulted in lesser air mass flow rate due to its lesser volume flow rate.

1.9 Power

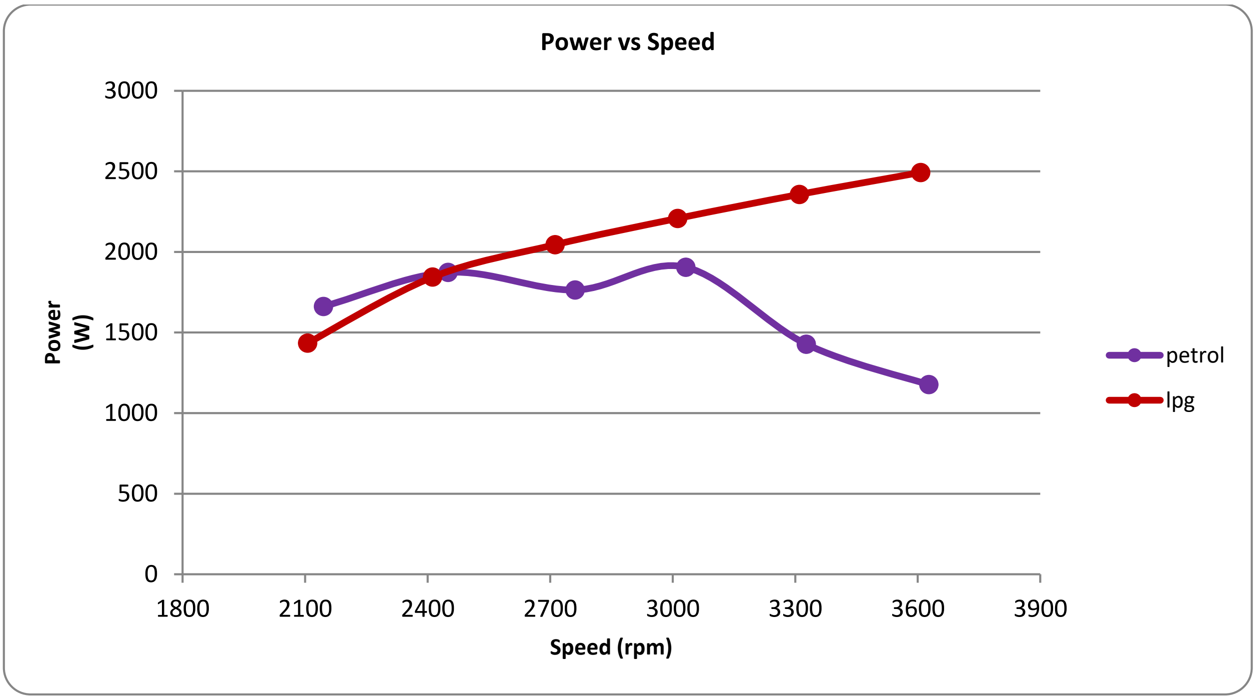

Figure 0.3 - Power against speed

Table 0.6 - LPG's power deviation from petrol value

Speed (rpm)	2100	2400	2700	3000	3300	3600
% Change	-14	-2	16	16	65	112

LPG resulted in a higher power in all the experimental speeds except at 2100 rpm and at 2400 rpm.

At 2100 rpm, power decreased by 14%.

At 2400 rpm, power output for petrol and LPG was almost equal.

As speed increased to 2700 rpm, to 3000 rpm, to 3300 rpm and to 3600 rpm; power increased by 16%, 16%, 65% and 112% respectively.

At 2700 rpm and at 3000 rpm, the increase in brake power was relatively small as compared to the increase observed at speeds of beyond 3000 rpm.

Beyond 3000 rpm, power increase was very rapid: and at 3600 rpm, power generated by LPG was more than double that produced by petrol.

Because of LPG's gaseous nature, it had improved fuel distribution throughout the combustion chamber as compared to petrol. A more uniform fuel distribution caused a more stable combustion of fuel-air mixture that led to a higher in-cylinder temperature and pressure in the LPG-fuelled engine. This, in addition to the higher heat of combustion possessed by LPG, resulted in greater power output as in-cylinder pressure was also directly proportional to brake power.

LPG's better fuel distribution and stable combustion also contributed to the smoother acceleration it showed when compared to that of petrol. This was observed in their respective power profiles where; petrol produced a sharp decline in power output at speeds beyond 3000 rpm whereas LPG exhibited a steady rise in brake power.

1.10 Exhaust gas temperature

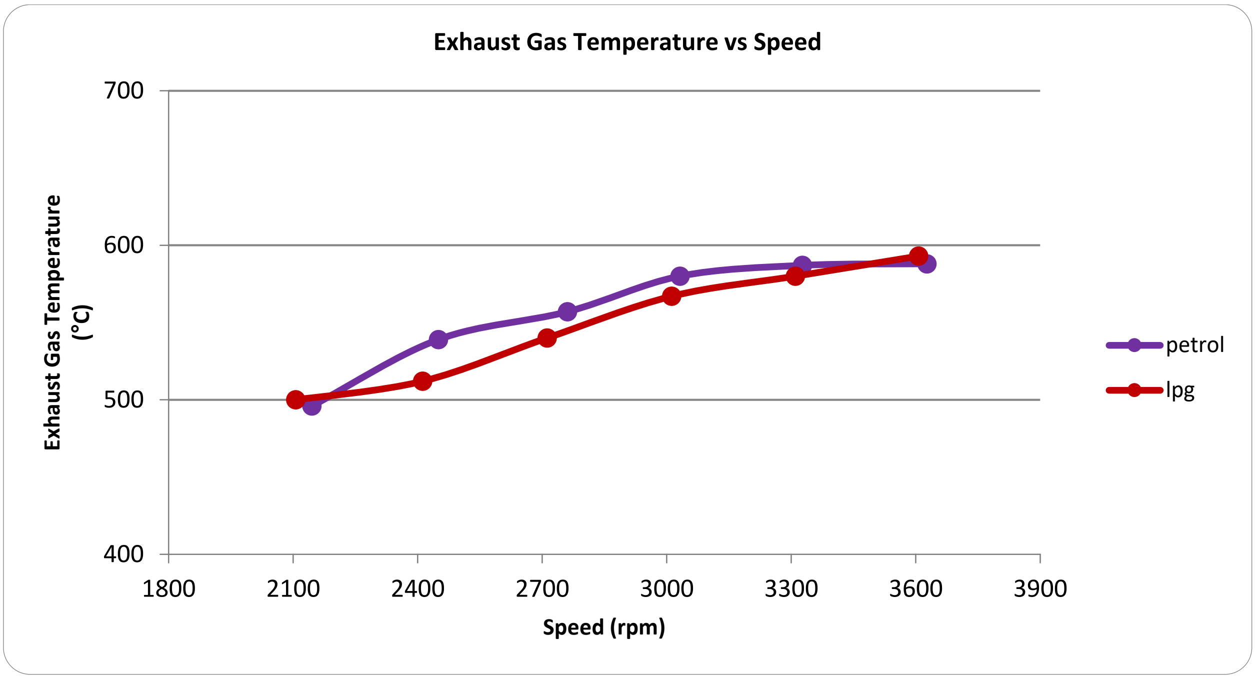

Figure 0.4 - Exhaust gas temperature against speed

Table 0.7 - LPG's exhaust gas temperature deviation from petrol value

Speed (rpm)	2100	2400	2700	3000	3300	3600
% Change	1	-5	-3	-2	-1	1

LPG resulted in a lower exhaust temperature in all the experimental speeds except at 2100 rpm and at 3600 rpm.

At 2100 rpm, exhaust gas temperature increased by 1%.

As speed increased to 2400 rpm, to 2700 rpm, to 3000 rpm and to 3300 rpm: exhaust gas temperature reduced by 5%, 3%, 2% and 1% respectively.

Then at 3600 rpm, the exhaust temperature increased again by 1%.

The largest decrease in exhaust temperature was at 2400 rpm.

Petrol was observed to possess a higher energy density of 34.2 MJ/L compared to LPG's energy density of 26 MJ/L.

During each intake stroke, LPG displaced 15-20% more air than petrol.

If the volume of air displaced by petrol was taken to be 'V' litres, then the maximum volume of air displaced by LPG would be '1.2V' litres.

The heat value of petrol in such a scenario would be expressed as:

$$(34.2 \times V)\ MJ = (34.2V)\ MJ$$

And the heat value of LPG would be expressed as:

$$(26 \times 1.2V)\ MJ = (31.2V)\ MJ$$

The above illustration shows that petrol combustion yielded more heat energy than LPG combustion, despite LPG having displaced a greater volume of air than petrol during the intake stroke. The higher heat energy produced from combustion of petrol gave rise to higher exhaust temperatures as compared to LPG.

Also, the air-fuel ratio could not be controlled directly in this instance of LPG introduction at the carburettor's throat. There was a possibility of oversupply of LPG that made the air-fuel mixture drawn into the combustion chamber too rich. Lesser air, which meant lesser oxygen in the combustion chamber might have led to incomplete combustion of the charge, hence lesser heat energy production and reduced maximum in-cylinder temperature.

This also, could explain the lower exhaust gas temperature recorded with LPG as fuel in comparison with that recorded with petrol as fuel.

1.11 Brake mean effective pressure (BMEP)

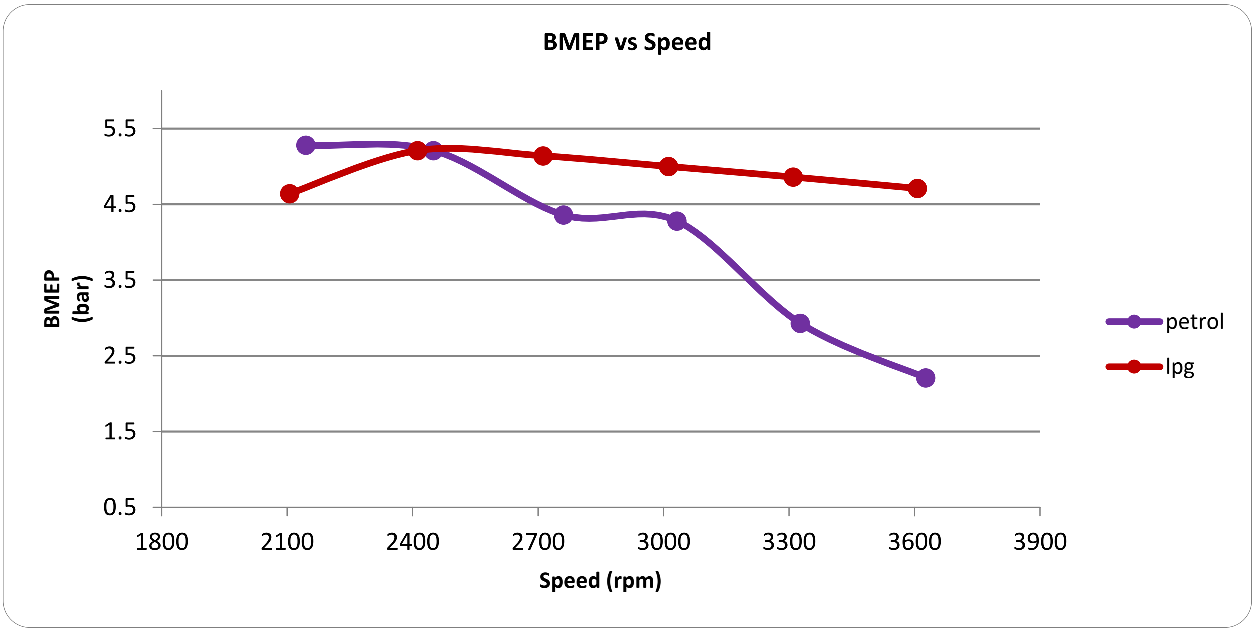

Figure 0.5 - BMEP against speed

Table 0.8 - LPG's BMEP deviation from petrol value

Speed (rpm)	2100	2400	2700	3000	3300	3600
% Change	-12	0	18	17	66	113

LPG resulted in a higher BMEP in all the experimental speeds except at 2100 rpm and at 2400 rpm.

At 2100 rpm, BMEP decreased by 12%.

At 2400 rpm, BMEP value was the same for both petrol and LPG.

As speed increased to 2700 rpm, to 3000 rpm, to 3300 rpm and to 3600 rpm; BMEP increased by 18%, 17%, 66% and 113% respectively.

At 2700 rpm and at 3000 rpm, the increase in BMEP was relatively small when compared to the increase observed at speeds exceeding 3000 rpm.

Beyond 3000 rpm, BMEP increase was very rapid: and at 3600 rpm, BMEP for LPG was more than double that of petrol.
For the case of LPG, volume of air displaced by the fuel was 15-20% greater than that displaced by petrol during suction. This resulted in a greater volume of LPG in the combustion chamber as compared to the volume of petrol in the combustion chamber. In addition to LPG having a greater volume than petrol, it also had a higher heating value of 46.67 MJ/kg compared to petrol's heating value of 43.44 MJ/kg. The outcome of this was a higher in-cylinder temperature in the case of LPG upon ignition.

The higher temperatures caused much more increased kinetic energy of molecules hitting the walls of the combustion chamber; thus giving rise to higher in-cylinder pressure in the LPG-fuelled engine.

1.12 Volumetric efficiency

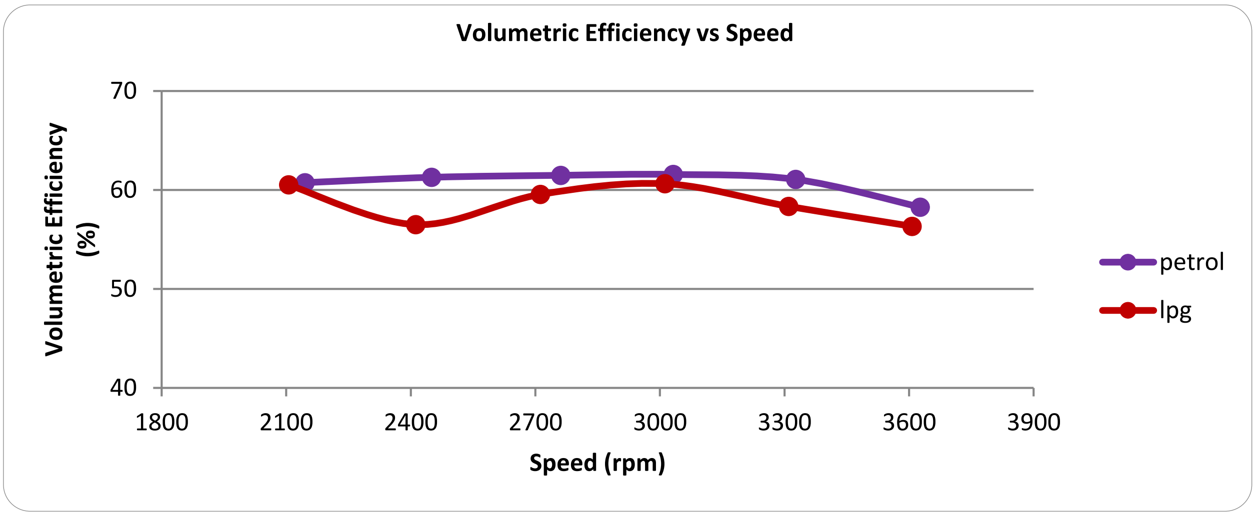

Figure 0.6 - Volumetric efficiency against speed

Table 0.9 - LPG's volumetric efficiency deviation from petrol value

Speed (rpm)	2100	2400	2700	3000	3300	3600
% Change	0	-8	-3	-2	-4	-3

LPG resulted in a lower volumetric efficiency in all the experimental speeds: only that at 2100 rpm, the reduction was so minimal, and the petrol and LPG efficiencies were very close to each other.

At 2400 rpm, the largest decrease in volumetric efficiency was observed at 8% reduction.

At 2700 rpm, 3000 rpm, 3300 rpm and 3600 rpm, the percentage reduction in volumetric efficiency was similar.

These reductions were due to absence of intake charge cooling due to vaporization. Petrol being a liquid fuel, underwent vaporization at the carburettor throat, at the throttle, at the intake manifold and at the inlet valve. The result of this vaporization was increased density of the fuel-air mixture entering the combustion chamber – an occurrence that did not take place in the case of LPG as it was already in a gaseous form.

This meant that LPG-air mixture inducted into the combustion chamber had a lower mass density as compared to petrol-air mixture taken in during a similar suction process.

Since volumetric efficiency is the ratio of the mass density of the fuel-air mixture drawn into the cylinder at ambient pressure (during intake) to the mass density of the same volume of air in the intake manifold; then LPG with its less dense charge was sure to yield lower values of volumetric efficiency in comparison with petrol.

Also, LPG being in a gaseous state at ambient pressure and temperature conditions meant that fuel occupied a larger volume in the fuel-air mixture. This caused displacement of more fresh air and a further reduction in volumetric efficiency.

Conclusion

Modern technology has proved a useful addition in the study of engine parameters. Sensors, thermocouples and the VDAS software enabled efficient data acquisition, analysis and storage with a low-level skill requirement; as evidenced by the matching results obtained from manual computation of air mass flow rate, and from the computer's calculation of the same.

Liquefied petroleum gas is a viable alternative to petrol in SI engine operations as it generated greater power and higher torque in comparison with petrol. It also exhibited higher BMEP than petrol. This study may pave the path for LPG incorporation in domestic machines such as lawnmowers and power saws.

LPG is a stable fuel as shown by its power plot which evinces a steady combustion throughout the entire experimental speed range. This contributes directly to reduced vibrations during engine operation; and from a commercial perspective, this reduces on maintenance cost.

Recommendations

For exhaust gases, only temperature was measured. It may be suggested that future investigations on petrol and LPG engine operations include emission tests; in line with the growing awareness on effects climate change.

Maximum cylinder temperature and pressure under LPG operation can damage the engine’s structural components; because the engine was designed to run on petrol, which has a lower heating value as compared to LPG. It is therefore advisable that similar tests be carried out at low to moderate speeds.

In this study, petrol and LPG were investigated separately; and were both found to be useful. This should spur further research, and a look into LPG-Petrol blends; as a basis for dual fuel operation.

LPG passed the test as a useful gaseous fuel in powering SI engines. Further tests involving other gaseous fuels e.g. biogas or Compressed Natural Gas (CNG) may be encouraged to ease overreliance on petrol.

With gaseous LPG’s introduction at the carburettor’s throat, a decrease in volumetric efficiency was observed. A system for liquid LPG’s direct injection into the intake manifold may be incorporated: as the resultant cooling effect from vaporization of LPG would increase the density of charge entering the cylinder; hence improved volumetric efficiency.

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