Journal of Electronics, Computer Networking and Applied Mathematics
ISSN: 2799-1156
Vol: 02, No. 01, Dec 2021 -Jan 2022
http://journal.hmjournals.com/index.php/JECNAM
DOI: https://doi.org/10.55529/jecnam.21.29.43

Enhancement and Analytical Assessment of Single-Cylinder Spark Ignition Engine Operated on Liquefied Petroleum Gas (LPG)

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Received: 26 September 2021 **Accepted:** 13 December 2021 **Published:** 30 January 2022

Abstract:** Utilizing gaseous fuels, such as Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG), has become widespread in the realm of commercial vehicles. This undertaking is driven by the primary goal of adapting an existing gasoline-fuelled Spark Ignition (SI) engine to seamlessly operate with LPG. Simultaneously, the secondary aim of this Endeavor involves a meticulous examination of the theoretical performance of the engine when fuelled with both LPG and gasoline. A comprehensive analytical comparison has been conducted to scrutinize the engine's performance under these diverse fuel scenarios. The engine under consideration for this scholarly pursuit is a four-stroke single-cylinder 7 kW TVS King Bajaj engine. To achieve the desired modification, a meticulously chosen first-generation LPG conversion kit has been identified and seamlessly integrated into the existing gasoline-fuelled engine. This conversion kit comprises essential components such as a mixing unit, pressure regulator, vacuum lock-off and filter, selector switch, solenoid valve, multi-functional valve, and LPG cylinder. After the successful adaptation of the engine to run on both fuels, it was mounted on a water dynamometer to systematically assess its performance and emission characteristics. The outcomes of the analytical engine performance evaluation are remarkable. The brake power output exhibited an impressive 7.2% improvement, coupled with a noteworthy 1.98% reduction in brake-specific fuel consumption when the engine operated on LPG instead of gasoline. Moreover, when running on LPG, the engine's brake thermal efficiency experienced a commendable boost of 2.66%. These discerning parametric analyses underscore LPG as an up-and-coming alternative to gasoline, not only in terms of performance but also in consideration of anti-knock properties, emission characteristics, and the cost-effectiveness of the fuel.

***Keywords:** SI Engine, Four Strokes, LPG, Gasoline.*

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1. INTRODUCTION

Background of the Study

Air pollution resulting from exhaust emissions produced by internal combustion (IC) engines has emerged as a formidable global concern, given its association with respiratory diseases and cancer. The pervasive issue of poor ambient air quality, particularly prevalent in urban areas with heightened automobile emissions, has fuelled the urgency for stringent regulations. These emissions not only contribute to health issues but also precipitate environmental challenges such as acid rain and global warming. Consequently, there has been a robust push towards enhancing regulations governing IC engine emissions, prompting intensive research into alternative fuels capable of mitigating harmful exhaust emissions without compromising thermal efficiency[1].

In tandem with the emissions predicament posed by IC engines, the escalating costs of fossil fuels pose a concomitant challenge. The world's heavy reliance on petroleum fuels for transportation and agricultural machinery has engendered price fluctuations and supply uncertainties, largely dictated by a handful of petroleum-producing nations. Faced with this volatility, nations are actively exploring alternative fuels that can be domestically produced, reflecting a strategic shift towards energy independence. One notable alternative gaining traction is liquefied petroleum gas (LPG), which has gained widespread usage in countries such as Italy, Turkey, Russia, and Korea. While commonly used in passenger cars, LPG has found application in a diverse range of vehicles, including vans, trucks, and buses, with notable instances in the United States, South Korea, Spain, and Vienna. The distinctive characteristics of LPG, composed mainly of propane and butane, position it as an attractive alternative. Its high-octane value makes it well-suited for high compression ratios, and its lower density and stoichiometric fuel air ratio contribute to reduced specific fuel consumption. Additionally, LPG's higher ignition temperature and octane rating prevent knocking, offering operational advantages. Beyond performance benefits, LPG presents environmental advantages, including lower exhaust emissions, cost savings of up to 60% compared to petrol, and the potential for extended engine life. This research project specifically focuses on the modification of a single-cylinder SI engine in a three-wheeler, aiming to demonstrate its practical viability as a dual-fuel system using both gasoline and LPG[2].

2. METHODOLOGY AND MATERIALS

To convert gasoline vehicles to propane vehicles, relatively inexpensive conversion kits are used, which include a pressure regulator/vaporizer that converts liquid propane to gaseous form and an air-fuel mixer that meters and mixes fuel with filtered intake air before drawing the mixture into the combustion chamber. LPG vehicles also require a unique fuel tank that is sturdy enough to handle the LPG storage pressure of around 10 bar. Carburetor modification is required, specifically drilling a hole between the throttle butterfly and the engine inlet. Then, tighten the vacuum nozzle and check for leaks. Then, tighten the mixer on the carburetor and check the nozzle direction. Replace the carburetor and position the pressure regulator/reducer in the correct location, near to the mixer but 150 mm from the exhaust and sparkplug. Place

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the cylinder on the vehicle's tire wall. Depending on the cylinder valve, a regulator can be utilized; the output pressure of this regulator is 0.276 bar [12].

Connect the pipe from the LPG cylinder to the entrance of the pressure regulator, then connect the pipe from the pressure regulator's outlet to the LPG mixer. Connect the carburetor's vacuum pipe to the pressure regulator. Then, after starting the engine with gasoline, turn off the gasoline supply. Because LPG is held in liquid form under high pressure, it must be vaporized before being brought into the combustion chamber. LPG is held in a composite vessel at high pressure and supplied to the engine via a regulator or vaporizer, which transforms the LPG to vapor. The vapor is sent to a mixer near the intake manifold, where it is metered and blended with filtered air before entering the combustion chamber [13].

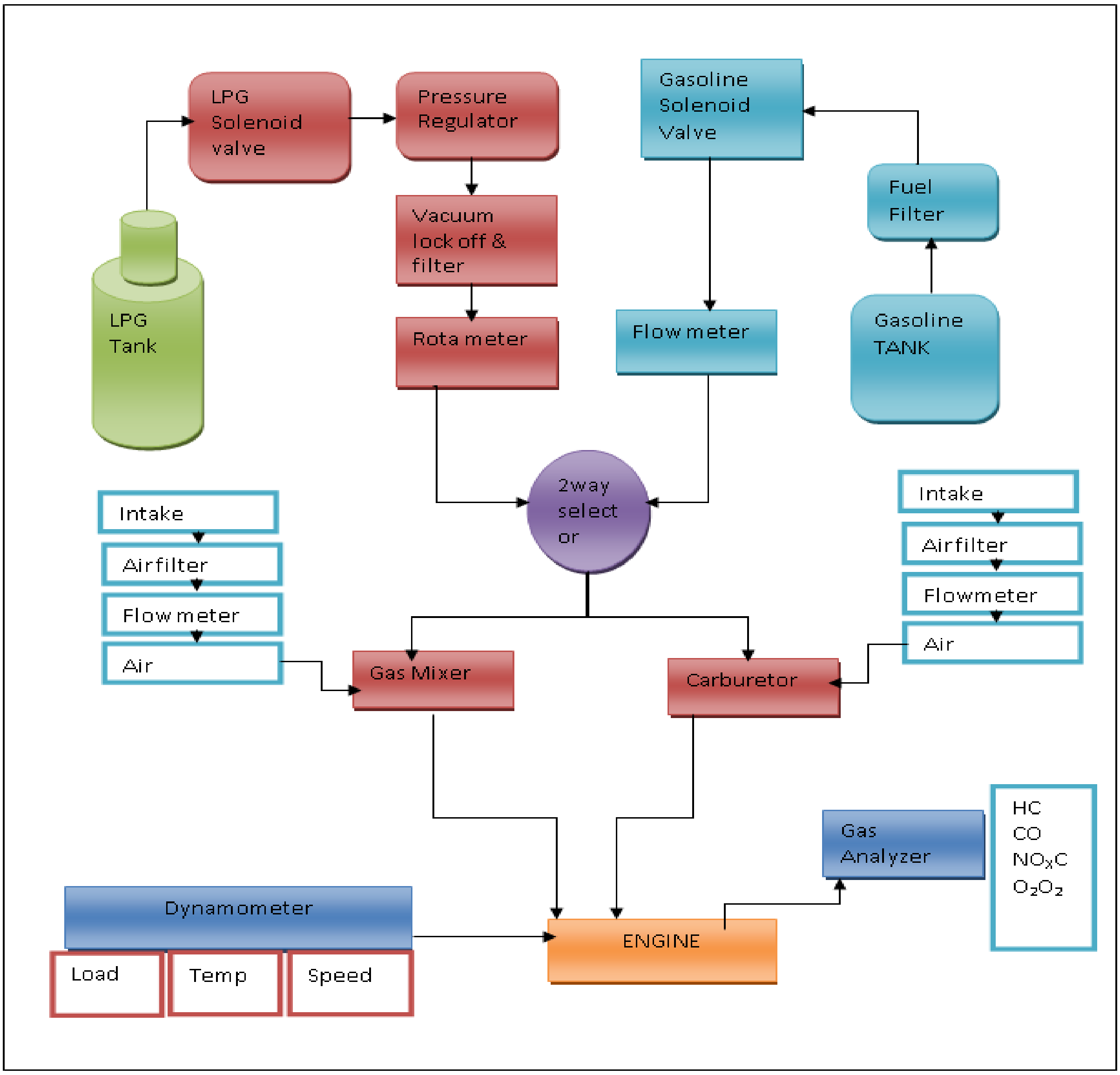

Figure 1. Layout of Experimental setup

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2.1 Stoichiometric Air-Fuel Ratio Calculation

It is critical to achieve fuel economy in an internal combustion engine (ICE) during operation. The right air-fuel ratio is critical for efficient fuel combustion in ICE. Fuel combustion is essentially an interaction of fuel with oxygen in the air. It is critical to understand the air-fuel ratio at which all available oxygen is used to completely burn the fuel, or at least the best attainable number. This is known as the stoichiometric air-fuel ratio. The air fuel ratio is a fuel attribute and chemical composition that defines the value for this ratio. In this topic, we will attempt to compute the stoichiometric air-fuel ratio for gasoline and LPG (pure propane, butane, or a mixture of the two)[3].

2.1.1 Calculating Stoichiometric Air-Fuel Ratio for Gasoline Fuel

The general formula to calculate the stoichiometric air-fuel ratio for any fuel is [12]:

$$C_xH_y + \left[x + \frac{y}{4}\right](O_2 + 3.76N_2) \longrightarrow xCO_2 + \frac{y}{4}H_2O + 3.76\left(x + \frac{y}{4}\right)N_2 \qquad (2.1)$$

The stoichiometric air-fuel ratio can be calculated by:

$$\left.\frac{A}{F}\right|_{st} = 4.76\left(x + \frac{y}{4}\right)\frac{M_{W,air}}{M_{w,fuel}} \qquad (2.2)$$

Where x is number of carbon atom, y is number of hydrogen atom and M_w is molecular weight. For gasoline (C_8H_{18}) fuel stoichiometric air-fuel chemical reaction is determined as follows;
$C_8H_{18} + 12.5\ (O_2 + 3.76N_2) \rightarrow 8\ CO_2 + 9\ H_2O + (12.5)\ 3.76\ N_2$,

Here the composition of air is considered by volume: N_2 = 79 %, O_2 =21 % and x = 8, y = 18
Since atomic weight of Carbon = 12.008, Oxygen = 16, Hydrogen = 1.008 and Nitrogen = 14.0
Molecular weight of air is =28 mol/kmol and molecular weight of octane fuel (12 x 8 + 1 x 18) is 114, [3]

Hence stoichiometric air-fuel for gasoline become:

$$\left.\frac{A}{F}\right|_{st} = 4.76\left(8 + \frac{18}{4}\right)\frac{28}{114} = 14.7:1 \qquad (2.3)$$

2.1.2 Calculating Stoichiometric Air-Fuel Ratio for Propane Fuel

Stoichiometric air-fuel ratio, the chemical reaction becomes[3]:

$C_3H_8 + 5(O_2 + 3.76\ N_2) \rightarrow 3CO_2 + 4H_2O + (5)3.76N_2$
Using equation 3.1 since, x = 3 and y = 8
$C_3H_8 + 5O_2 + 18.8N_2 \rightarrow 3CO_2 + 4H_2O + 18.8N_2$

Molecular weight of propane = (12×3) + (1×8) = 44 and molecular weight of air is 28,
Hence stoichiometric air-fuel ratio of propane is calculated as:

$$\left.\frac{A}{F}\right|_{st} = 4.76\left(3 + \frac{8}{4}\right)\frac{28}{44} = 15.14 : 1 \qquad (2.4)$$

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2.1.3 Calculating Stoichiometric Air-Fuel Ratio for Butane Fuel

Again, stoichiometric air-fuel ratio, chemical reaction written as:

$$C_4H_{10} + 6.5(O_2 + 3.76N_2) \rightarrow 4CO_2 + 5H_2O + (6.5)3.76N_2,$$

hence x = 4 and y = 10, the reaction simplified as:
$C_4H_{10} + 6.5O_2 + 24.5N_2 \rightarrow 4CO_2 + 5H_2O + 24.5N_2$,

Molecular weight of air is 28 and molecular weight of Butane = (4x12) + (1x10) =58, then stoichiometric air-fuel ratio given as [3]

$$\left.\frac{A}{F}\right|_{st} = 4.76\left(4 + \frac{10}{4}\right)\frac{28}{58} = 14.9:1 \quad (2.5)$$

2.1.4 Calculating Air-fuel Ratio for 70% Propane and 30% Butane

Most LPG fuel contains 70% propane and 30% butane. The air-fuel ratio for this combustion process is written as follows[3].

For 70% of Propane the complete combustion process written using (3.1) as follows
$0.7C_3H_8 + (0.7)\,5O_2 + (5)\,3.76N_2 \rightarrow (0.7)\,3CO_2 + (0.7)\,4H_2O + (5)\,3.76N_2$
$0.7C_3H_8 + 3.5\ O_2 + 18.8N_2 \rightarrow 2.1\ CO_2 + 2.8H_2O + 18.8N2$ then air-fuel ration become from equation 3.2

$$\left.\frac{A}{F}\right|_{st} = 0.7 \times 4.76\left(3 + \frac{8}{4}\right)\frac{28}{44} = 10.598:1$$

For 30% of Butane the complete combustion reaction becomes using equation 3.2
$0.3C_4H_{10} + 0.3(6.5)\ O_2 + (6.5)3.76N_2 \rightarrow 0.3(4)CO2 + 0.3(5)\ H2O + (6.5)3.76N_2$
$0.3C_4H_{10} + 1.95O_2 + 24.5N_2 \rightarrow 1.2CO_2 + 1.5H_20 + 24.5N_2$, then air-fuel ratio given as from above equation 3.2

$$\left.\frac{A}{F}\right|_{st} = 0.3 \times 4.76\left(4 + \frac{10}{4}\right)\frac{28}{58} = 4.5:1$$

Hence stoichiometric air fuel ratio for 70% of propane and 30% of Butane is 15.09:1.
The air-fuel ratio for Gasoline and LPG is above by using this air-fuel ratio we calculate various operating parameters.

2.2 Determination of Mixture Calorific Value

Here we try to calculate calorific value of LPG fuel based on calorific value of propane and butane from fuel calorific value data[3].
Calorific value (Q_{lhv}) of propane (C_3H_8) = 46300 KJ/kg
Calorific value (Q_{lhv}) of Butane (C_4H_{10}) = 45700 KJ/kg
For different percentage composition of propane and butane calorific value determined as follows.
Total Calorific value of mixture composition 70% propane and 30% butane is give as;

$$Q_{lhvmix} = 0.7\times Q_{lhv}(C_3H_8)v + 0.3\times Q_{lhv}(C_4H_{10}) \quad (3.6)$$

$Q_{lhvmix} = 0.7\times46300KJ/kg + 0.3\times45700\ KJ/kg$

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Q_{lhvmix}= 46120 KJ/kg , Similarly for different percentage composition of propane and butane total calorific value calculated below the table.

Table 1. Calorific value of LPG for difference percentage composition

Propane (C_3H_8)(%)	**Butane (C_4H_{10})(%)**	**($Q_{lhv total}$) (KJ/kg)**
1	0	46300
0.9	0.1	46240
0.7	0.3	46120
0.6	0.4	46060
0.5	0.5	46000
0	1	45700

Since Gasoline has a calorific value of 43000 KJ/kg. From this table the calorific value of LPG is higher than gasoline and this means LPG can be liquefied in low pressure range (0.7-0.8MPa) at atmospheric pressure**.**

2.2.1 Analytical Determination of Engine Performance Parameters

Here theoretically we calculate Brake torque, Brake power, and specific fuel consumption brake thermal efficiency and indicated thermal efficiency for these single-cylinder spark ignition engine. Brake power is output power measured at the crankshaft. Brake-specific fuel consumption is a measure of how efficiently the fuel supplied to the engine is used to produce power. Brake thermal efficiency is the ratio of power produced to the energy in the fuel burned to produce this power. From engine specification data parameters are given as follows[3].

Table 2. Data given from engine specification.

$N@_{Pbmax}$	5500 rpm
P_{bmax}	7kw
$N@_{Tbmax}$	3500rpm
$N@_{min}$	800rpm
T_{bmax}	15.04 Nm
$b_{sfc@P_{bmax}}$	$270^{g}/_{kwh}$

From Table 3.3 the data give are; -
T_{max}= 15.04Nm, P_{max} = 7KW already we get from engine specification data for Bajaj engine $N@T_{max}$= 3500rpm, and N@Pmax=5500rpm

$$N_{@Pbmax=\ 5500rpm}$$

2.2.2 Determination of Brake power using operating parameters for Gasoline Engine

The amount of heat generated ($\dot{Q}_{in}$) during the combustion can be estimated by [12]:

$$\dot{Q}_{in} = \eta_c \times \dot{m}_f \times Q_{lhv} \qquad (2.7).$$

Where $\dot{Q}_{in}$ is heat flow rate to the engine (Kw) η_c is fuel conversion efficiency (%), $\dot{m}_f$is mass flow rate of fuel(kg/s)

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$\dot{m}_a$= mass flow rate of air (kg/s) and $Q_{lhv}$is calorific value of the fuel (kJ/kg).
Mass flow rate of air inducted in to the engine can be determined by:

$$\dot{m}_a = \eta_v \times \rho_a \times V_s \times n \tag{2.8}$$

Where η_v is volumetric efficiency (%), $\rho_a$is density of air and n = number of crankshaft revolution and n = $\frac{N}{2}$ for four strokes [3].
Then the mass flow rate of fuel can be detrmined from the stociometric Air-Fuel ratio as follows:

$$\dot{m}_f = \dot{m}_a \times \left.\frac{F}{A}\right|_{st} \tag{2.9}$$

Substituting equation 3.8 and 3.9 in equation 3.7, it becomes:

$$\dot{Q}_{in} = \eta_c \times \eta_v \times \rho_a \times V_s \times n \times \frac{F}{A} \times Q_{lhv} \tag{2.91}$$

there for relation between heat generated to the engine and
Brake power (P_b) given as :

$$P_b = \eta_m(\eta_{ith} \times \dot{Q}_{in}) \tag{3.92}$$

Where η_m is mechanical efficiency and η_{ith} is indicated thermal efficiency.
Then substituting equation 10in to equation 11, brake power relation becomes:

$$P_b=\eta_m \times \eta_{ith} \times \eta_c \times \eta_v \times \rho_a \times V_s \times n \times \frac{F}{A} \times Q_{lhv} \tag{2.63}$$

Assume that: η_c= 95%, η_v= 80% , η_m =85% and η_{ith}= 35%
Density of air can be computed from:

$$\rho_a= \frac{P_{atm}}{R \times T} = \frac{101.235kPa}{0.287kj/kmol \times 298K}= 1.18 \text{ kg/m}^3 \tag{2.94}$$

Stoichiometric Fuel- Air ratio can be taken as the reciprocal of stoichiometricA/F:

$$\left.\frac{F}{A}\right|_{st} = \left(\left.\frac{A}{F}\right|_{st}\right)^{-1} \tag{2.95}$$

For gasoline it will be:

$$\left.\frac{F}{A}\right|_{st} = (14.7)^{-1} = 0.068$$

Therefore, the brake power output for stoichiometric combustion of gasoline fuel will be:
P_b= 0.85×0.35×0.95×0.8×1.18×0.00019916×45.833×0.068×43000
P_b= 7 kW
This value is the same as the engine specification given by the manufacturer. The brake power of the engine at any other engine speed (N) can be determined by using the following empirical relation:[12].

$$P_b\,(N) = P_{b,max}\left(\frac{N}{N_{P_{b,max}}}\right)\left[1 + \left(\frac{N}{N_{P_{b,max}}}\right) - \left(\frac{N}{N_{P_{b,max}}}\right)^2\right] \quad (2.96)[3].$$

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Where $N_{P_{b,max}}$ is the engine speed corresponding to the maximum brake power for selected TVS three-wheeler engine this value is 5500 rpm as indicated in Table 3.3The maximum brake specific fuel consumption can be determined at maximum brake power using the relation given by [12].

$$b_{sfc} = \frac{\dot{m}_f}{P_b}(g/kWhr) \tag{2.97}$$

For gasoline fueled engine the maximum b_{sfc} can be determined as follows:

$$b_{sfc,max} = \frac{0.000586 \times 3600 \times 1000}{7kW} = 278\ g/kWhr$$

The above calculated b_{sfc} at maximum brake power is similar with the engine specification given in Table 3.3
The b_{sfc} corresponding to various engine speed (N) can be calculated by:[12].

$$b_{sfc}\,(N) = b_{sfc,max}\left(\frac{N}{N_{P_{b,max}}}\right)\left[1.2 + \left(1.2 \times \frac{N}{N_{P_{b,max}}}\right) - \left(\frac{N}{N_{P_{b,max}}}\right)^2\right] \quad (2.98)[3].$$

The engine speed corresponding to the maximum torque is determined by:

$$N_{@Tbmax} = (0.5 - 0.8)N_{@Pbmax} \tag{2.99}$$

The maximum engine (N_{max}) can be obtained from the relation with the engine speed at maximum brake power ($N_{@pbmax}$):

$$N_{@pbmax} \approx (0.85 \text{ to } 0.95)N_{max} \tag{2.1.0}$$

From Table 3.3 the $N_{@Tbmax}$ can be taken as 3500 rpm. The minimum engine speed for SI engine varies from 600 – 1000 rpm, for the present work it is assumed that N_{min} is 800 rpm. The maximum engine speed is determined as:

$$N_{max} = \frac{N_{@Pbmax}}{0.88} = \frac{5500}{0.88} = 6250\ rpm$$

Therefore, for selected engine speed between the minimum (800 rpm) and maximum (6250 rpm) points the corresponding brake power (p_b), engine torque (T_e), brake mean effective pressure (b_{mep}) and brake specific fuel consumption (b_{sfc}) are calculated and the results are tabulated in Table 3.4.

Table 3. Computed engine performance characteristics parameter for gasoline fouled SI engine

N (rpm)	**P_b(kW)**	**T_b(Nm)**	**b_{mep} (bar)**	**b_{sfc} (g/kWh)**
500	0.688956	4.388253	2.344519	2.967769
1000	1.462059	4.656236	2.487696	2.740165
1500	2.287754	4.857226	2.595078	2.55719
2000	3.134485	4.99122	2.666667	2.418843
2500	3.970699	5.058213	2.702461	2.325124

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3000	4.764838	5.058213	2.752461	2.276033
3500	5.485349	4.99122	2.833333	2.27157
4000	6.100676	4.857227	2.757271	2.311736
4500	6.579264	4.656237	2.643177	2.396529
5000	6.889557	4.388253	2.491051	2.52595
5500	7	4.05327	2.300895	2.7
6000	6.879038	3.651293	2.072707	2.918678
6500	6.495116	3.182321	1.806488	3.181983
7000	5.816679	2.646351	1.502237	3.489917

2.2.3 Determination of Brake thermal efficiency

Brake thermal efficiency of engine calculated as [12].

$\eta_{bth} = \frac{P_b}{\dot{m}_{f} \times Q_{LHV}}$ (3.1.1)[3].

$\eta_{bth} = \frac{7kW}{0.000586\ kg/s \times 43000}$

$\eta_{bth} = 27.78\%$

Indicated power given by

$P_i = \frac{P_b}{\eta_m} = \frac{7kW}{0.85}$

$P_i = 8.24$ kW and indicated thermal efficiency calculated by

$\eta_{ith} = \frac{P_i}{\dot{m}_{f} \times Q_{LHV}} = \frac{8.24\ kW}{0.000586 \times 43000}$ (3.1.2).

$\eta_{ith} = 32.7\%$

2.2.4 Determination of Engine Performance Parameters for LPG fouled SI Engine

Since we are using the same engine similar assumptions of operating parameters are taken but air-fuel ratio and calorific value of LPG fueled engine are different. The engine brake power can be calculated using equation (3.12). Similar with the case of gasoline fueled engine assume that $\eta_c = 95\%$, $\eta_v = 80\%$, $\eta_m = 85\%$ and $\eta_{ith} = 35\%$. Consider the stoichiometric Air-Fuel for LPG fuel contains 70 % by vol. propane and 30 % by vol. butane which is 15.14:1 as discussed in section 3.4.4. The corresponding stoichiometric Fuel-Air ratio can be determined using equation (3.13)[3].

For LPG

$$\left.\frac{F}{A}\right|_{st} = (15.14)^{-1} = 0.066$$

Therefore, the brake power of the engine when it run with LPG fuel will be:

$P_b = 0.85 \times 0.35 \times 0.95 \times 0.8 \times 1.18 kg/m^3 \times 0.00019916\ m^3 \times 2750/60 \times 0.066 \times 46300$

$P_b = 7.51kW$

The brake power of the engine at any other engine speed (N) can be determined by using the empirical relation given in equation (3.14)

Engine maximum brake specific fuel consumption can be determined by equation (3.15)

$$b_{sfc} = \frac{0.0005687 \times 3600 \times 1000}{7.51kW}$$

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= 272.61 g/kWhr

The brake specific fuel consumption corresponding to any other engine speed can be calculated using equation (3.16). Finally for the same engine speed interval N_{min} = 800 rpm and N_{max} = 5625 rpm the brake power, engine torque, brake mean effective pressure and brake specific fuel consumption are calculated and the results are tabulated in Table 3.5.

Table 4. Calculated engine characteristic parameters for LPG fueled SI Engine

N(rpm)	P_b(kW)	T_b(Nm)	b_{mep}(bar)	b_{sfc}(g/Whr)
500	0.688956	6.582379	4.149086	2.835868
1000	1.462059	6.984356	4.402465	2.61838
1500	2.287754	7.285839	4.592499	2.443537
2000	3.134485	7.486828	4.719189	2.311339
2500	3.970699	7.587322	4.782534	2.221785
3000	4.764838	7.587322	4.782534	2.174876
3500	5.485349	7.486828	4.719189	2.170612
4000	6.100676	7.285839	4.592499	2.208992
4500	6.579264	6.984356	4.402465	2.290017
5000	6.889557	6.582379	4.149086	2.413686
5500	7	6.079907	3.832362	2.58
6000	6.879038	5.476941	3.452293	2.788959
6500	6.495116	4.773481	3.008879	3.040562
7000	5.816679	3.969526	2.50212	3.33481

3. RESULT AND DISCUSSION

At various engine speeds, the stoichiometric air-fuel ratio, brake power, engine torque, brake mean effective, and brake specific fuel consumption are estimated analytically. This chapter compares these when the engine is running on gasoline and LPG fuels. It should be noted that LPG is composed of 70% propane and 30% butane by volume.

3.1 Brake Power

Figure 4.1 depicts the variation in brake power at various engine speeds when the identical engine is driven on gasoline and LPG. It has been proved that LPG engines provide more power than gasoline engines. The brake power of LPG is greater because it was injected in liquid form rather than gaseous form. The liquid injection will benefit from its energy content through better volumetric efficiency and quick vaporization, resulting in a cooler and denser air-fuel mixture flowing through the combustion chamber. Because LPG has a higher compression ratio, it produces more power than gasoline [9].

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DOI: https://doi.org/10.55529/jecnam.21.29.43

Then it lowers as engine speed increases due to decreased volumetric efficiency at higher speeds. Volumetric efficiency diminishes as the mass air inflow decreases with increasing speed. However, as demonstrated in the graph above, the LPG-fueled engine produces more power than the gasoline-fueled engine. The percentage increase in power output is 7.2% at higher speeds, while there is no change at lower speeds. Analytical results demonstrate that the value is connected to the above findings [9].

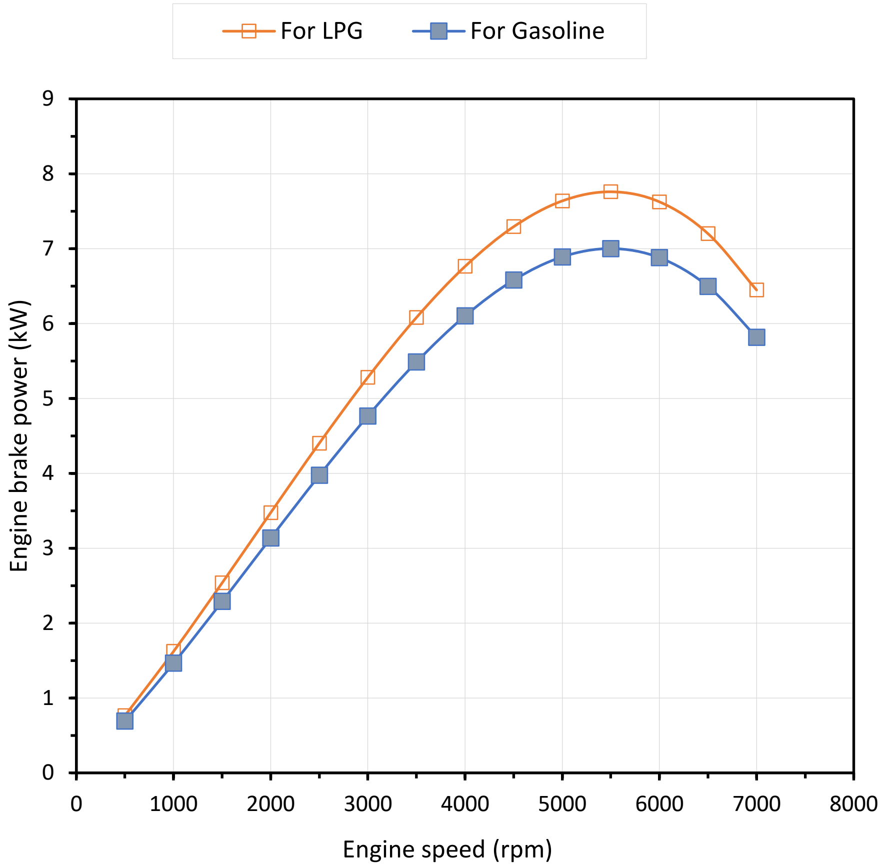

Figure 2. Brake power for LPG and Gasoline performance curve

3.2 Brake Torque

Figure 4.2 depicts the variation in brake torque with engine speed for both LPG and gasoline fuels when the same engine is used. It has been established that LPG engines have greater engine torque than gasoline engines. This is due to the fact that a higher compression ratio creates a bigger turning action on the cylinder crank. That means the engine is getting more push on the piston, resulting in increased torque. Another factor is that while LPG brake power is greater than gasoline, LPG torque increases as well, as they have a direct relationship [10].
As seen in the graph, the brake torque of both LPG and gasoline fuels is medium at low engine speeds and increases with engine rpm. With a low engine speed, the brake torque is modest and begins to grow with engine RPM, peaking at 3500rpm. It quickly drops at greater speeds. Throughout the process, LPG produces more torque than gasoline [10].

Journal of Electronics, Computer Networking and Applied Mathematics
ISSN: 2799-1156
Vol: 02, No. 01, Dec 2021 -Jan 2022
http://journal.hmjournals.com/index.php/JECNAM
DOI: https://doi.org/10.55529/jecnam.21.29.43

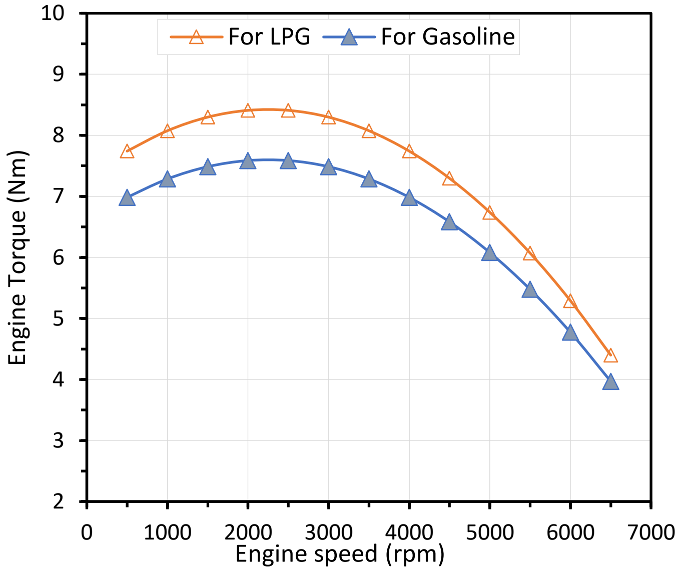

Figure 3. Engine torque for LPG and Gasoline performance curve

3.3 Brake Specific Fuel Consumption

As seen in Fig. 4.3, bsfc is higher at idle or low speed, and lower at high speed at mid-engine speed. LPG has a lower Bsfc than gasoline fuel. Fuel consumption is lowest at maximum brake torque and decreases by 4.15% and 1.98% when compared to gasoline fuel. The highest mass of fuel consumption with LPG calculated is 272.61 g/kwhr at 7.51 kW, and the maximum mass of fuel consumption with petrol calculated is 278 g/kwhr at 7 kW. Brake specific fuel consumption is lower for LPG fueled engines because it has higher calorific value than gasoline fuel. The calorific value of LPG has 46300 KJ/kg and for gasoline 43000 KJ/kg. This Analytical result is related with literature findings above they have got the same results [11].

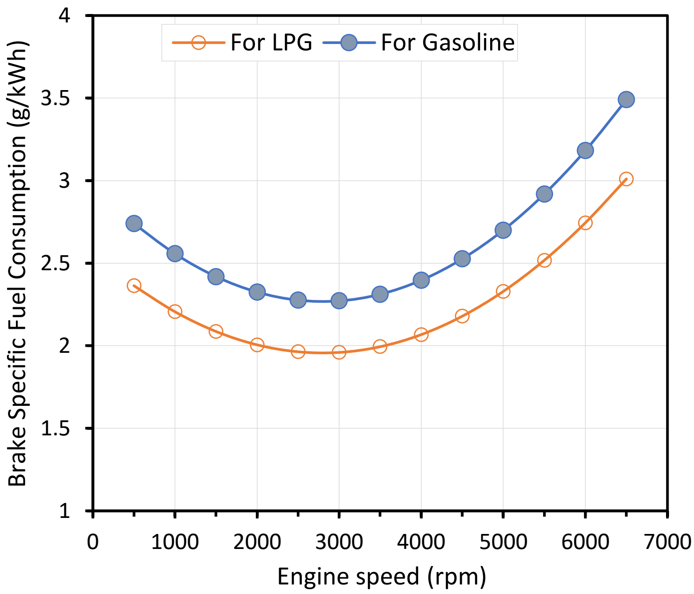

Figure 4. Brake specific fuel consumption for LPG and Gasoline performance curve

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3.4 Brake Mean Effective Pressure

The relationship between engine speed and brake mean effective pressure is depicted in Figure 4.4. The force that moves the piston from TDC to BDC during each stroke to generate brake to power. As demonstrated in the graph above, the effective pressure of LPG is higher than that of gasoline. The lower the engine speed, the higher the effective pressure, and the higher the engine speed, the lower the effective pressure. The curve is as follows: Brake torque begins to decrease when it reaches its maximum. This is because charge intake is optimized at a specific engine speed at which pressure is created. Because LPG has more torque, the braking mean effective pressure for LPG is higher than for gasoline [11].

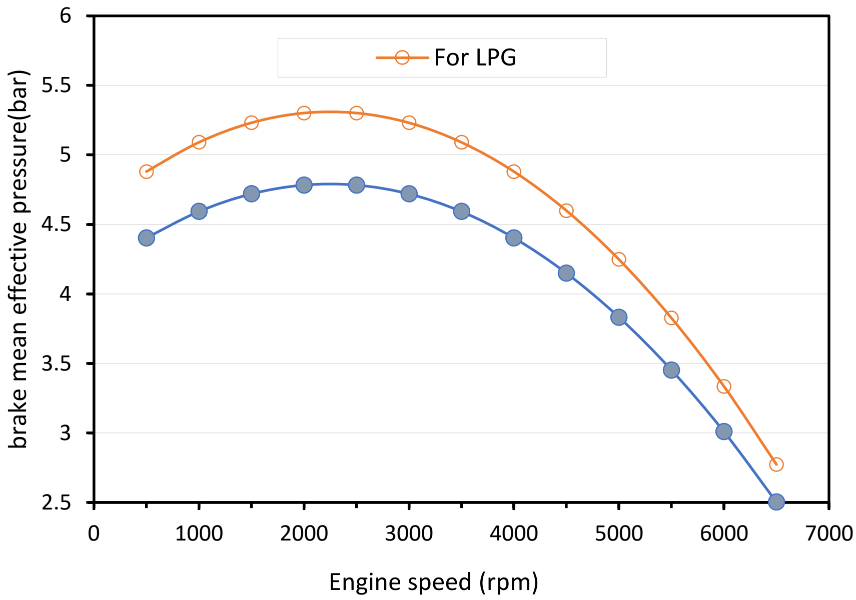

Figure 5. Brake mean effective pressure for LPG and Gasoline performance curve

3.5 Brake Thermal Efficiency

There is an increase in brake thermal efficiency, which leads to an increase in brake power for LPG-powered engines, as well as an increase in compression ratio for LPG-powered engines. The heat of compression facilitates improved mixing and evaporation of fuel by compressing available air and fuel combination to a smaller space. Increased combustion efficiency due to an increase in compression ratio indicates that combustion of fuel pays bigger returns in the form of more energy from fuel. As a result, there is more energy accessible. The largest compression ratio results in the highest thermal efficiency of the brake. Brake thermal efficiency is around 28.52% at full power for LPG-fueled engines and 27.78% for gasoline-fueled engines [14].

The percentage increment of brake thermal efficiency is almost 2.66%.It was clear that increasing inlet air temperature at the same time brake thermal efficiency increases at the same time LPG provides higher efficiency at low loads but petrol provides higher efficiency at high loads. Since LPG has higher octane number (112) which enables higher compression ratios to be employed and therefore gives more thermal efficiency [14].

4. CONCLUSIONS AND FUTURE WORK

According to the findings of this study, LPG fuel is a viable alternative fuel for spark ignition engines and the following findings have been reached.

- Analytical investigation revealed that fuel consumption is reduced by around 1.98% compared to gasoline use at 3500rpm. The brake specific fuel consumption increases during the engine cycle as engine speed increases.
- Brake power improves for both fuels up to the elastic working range. However, because LPG has a larger calorific value than gasoline, the compression ratio is increased. On the other hand, volumetric efficiency declined at first, causing the LPG fuel to evaporate. The gaseous nature of LPG takes up space and reduces the amount of air that enters.
- According to analytical calculations, LPG has a higher brake thermal efficiency than gasoline, with a percentage increase of roughly 2.6%. This is because, in the case of LPG, brake power increases, and brake thermal efficiency falls as brake power lowers. Improving dual-fuel engine brake thermal efficiency by advancing injection timing.
- Finally, the engine ran at various RPMs. It runs nicely at low, medium, and high speeds. Because LPG has a higher-octane level, the engine ran without knocking, disturbance, or excessive smoke. Based on our findings, we urge that the use of high-performance three-wheelers be expanded and grown in our country.

Future Work

- The engine's experimental performance characteristics will be investigated.
- With this innovative technology, a suitable LPG kit for a single cylinder can be produced.
- The technique will be expanded to include multi-cylinder engines and current SI engines.

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