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Experimental assessment of performance, emission and lube oil deterioration using gasoline and LPG for a sustainable environment

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ABSTRACT

The unfavorable environmental hazards by conventional fuels like gasoline have stirred scientists to pursue less detrimental and more effective fuels. Mostly, the oxygenated and biofuels produced higher CO_2 and NOx emissions due to improved combustion. These greenhouse gases are mainly responsible for global warming which is considered a serious environmental threat nowadays. Therefore, efforts need to be rendered to look for such alternative fuels which not only improve engine efficiency but also reduce hazardous emissions. Liquefied Petroleum Gas (LPG) has long been considered for improved engine performance and reduced harmful emissions. However, rare efforts have been made to evaluate fuel efficiency by assessing the damage imparted to lubricating oil. This existing gap has been filled by a thorough assessment of performance, manifold emissions, and the wearing of lube oil using gasoline and LPG in spark ignition (SI) engines. The fuels were investigated through vital parameters: brake power (BP), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), and exhaust emissions. Although LPG showed average lessened BSFC (15.13%) and increased BTE (14.34%), the gasoline kept itself in the competition by producing average 23.74% higher brake power. All the hazardous tailpipe emissions improved considerably for LPG. Similarly, the degradation of physical and chemical properties, the concentration of metallic particles, and the depletion rate of additives also favoured the gaseous fuel. The statistical significance of performance and emission terms with speed was figured out using the Pearson and Spearman correlation coefficient (R). BSFC and hydrocarbon Pearson concentration emerged negatively correlated to speed with values of −0.813 and -0.996, respectively, for LPG.

1. Introduction

Over the years, worsening air quality has become the subject of paramount importance. The increased concentration of airborne particles is associated with a surge in respirational and mental health issues [1]. Scientists have catered this alarming issue by

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suggesting the adaption of various potent ways. Of many recommendations, one is to decrease enormous vehicular emissions by replacing traditional fuels like gasoline and diesel without making a compromise on engine performance [2,3]. Moreover, the fast-depleting petroleum resources and fear of acute scarcity of energy-producing means in future has developed the urgent need for sustainable and environment-friendly fuel [4–6]. The term, alternative fuels, is generally associated with non-petroleum fuels. The recent time has seen exorbitant use of alternative fuels owing to their better fuel consumption, lesser exhaust of primary and secondary pollutants and economics aspects [7–9]. The idea of operating commercial vehicles on gaseous fuels has been getting accepted since the last two decades [10]. Among many such fuels, Liquefied Petroleum Gas has shown the capacity to be employed in the SI engine as a gasoline substitute. LPG is an amalgam of petroleum emitted gases stored at an optimum temperature to keep it in the liquid state. Its structure is chiefly composed of propane along with propylene, butylene and a minor number of hydrocarbons. The high octane number (104), dry nature, cleaner-burning and the higher ignition temperature of LPG has rendered it appropriate for spark-ignition engines [10,11]. Currently, the application of gaseous fuels in transportation sector (passenger cars and buses) is becoming prevalent. If the pertinent conditions are being fulfilled, the improved performance will be prominent, because of higher thermal capacity and homogeneity of gaseous phase [12].

Namar et al. [13] employed eleven regression models based on machine learning techniques in order to provide accurate and fast-response model for the forecast of combustion initiation. The prediction efficiency was improved from 89.3 to 98.4% in spite of nonlinear type of robust random sample consensus (RANSAC) and SAM (simple algebraic model). Indeed, due to the linear hypothesis (the correlation for combustion start prediction), the depicted models have an acceptable response time to be used in real-time control applications like the electronic control units in engines. Much literature has been published regarding the novel approach of operating engines like spark ignition (SI) and compression ignition (CI) engines on blends of various fuels [4,11,14–19]. The engines functioning on gasoline and LPG blends with renewable and non-renewable fuels has also been reported. Usman et al. investigated the impact of LPG and LPG-hydroxy mix on performance and emission parameters of SI engine and found that blended fuel's performance noticeably better [20]. Use of dimethyl ether and LPG blend has also shown the potential of substituting LPG [21]. Similarly, LPG-ethanol, ethanol-gasoline, methanol-gasoline, alcohol-gasoline and I-amyl alcohol gasoline mixtures have also been studied to find a suitable alternative having less consumption and manifold emission [7,22–25].

Patil et al. [26] investigated the impact of LPG on multi cylinder, 1089 cc engine performance. They compare the mechanical efficiency for both LPG and gasoline with various lubricant oils through Morse test. At 1750 rpm, they achieved 68.37%, 64.69%, and 65.75% mechanical efficiency in case of gasoline with SAE20E30, SAE20E50 and SAE 20W40 respectively. In case of LPG, they obtained 62.99%, 59.85% and 61.85% mechanical efficiency for SAE20E30, SAE20E50 and SAE 20W40 respectively. They inferred that the lower mechanical efficiency in case of LPG mainly because of power losses due to friction. They suggested lower viscosity oils in order to improve mechanical efficiency. They also validated their experimental results through regression based on mathematical model and regression based on artificial neural network (ANN). They found that engine speed is the most influential factor in determining the impact of fuels and they achieved regression coefficient of 0.9243 through ANN approach and 0.8920 through mathematical model. It indicated more accurate prediction through ANN approach. Duy et al. [27] conducted experiment on 109.5 cc motorcycle engine in order to evaluate performance of LPG fuel in comparison with gasoline. They modified intake manifold for LPG injector installation and inducted LPG at pressures of 0.8, 1, 1.2 and 1.4 bar with injector nozzle diameter of 1 mm. They obtained 69.94%, 46.48%, and 47.89% lower HC, NOx and CO emissions as compared to gasoline. Moreover, the average fuel (kg/100 km) were reduced by 14.78% and energy consumption (MJ/100 km) were reduced by 12.84% in case of LPG along with average 19.42% reduction in brake power at wheels.

Hashem et al. [28] conducted experiments for different loads (0, 25, 50, 75 and 100%) in terms of brake power and three distinct speeds (2400, 3000, 3600 rpm). The results revealed that LPG consumed 5.42% less as compared to gasoline, but the brake thermal efficiency and volumetric efficiency were also reduced by 4.52% and 5.93% in case of LPG. The CO and CO_2 emission were reduced by 11.54% and 14.44% in case of LPG respectively. However, the NOx emissions were increased by 8% in case of LPG. This increase in NOx emission in case of LPG mainly because of 7.8% and 14.9% increase in exhaust gas temperature and cylinder temperature. Simsek et al. [29] implanted response surface methodology (RSM) approach to evaluate the optimum performance in case of LPG and gasoline. They varied LPG ratio from 0 to 100% with interval of 25% under three distinct loads (2000, 2500 and 3000W). They found most optimum results for 35% LPG ratio and 2400W loading condition. The maximum BTE value under optimum condition was observed to be 25.77%, while the minimum BSFC, CO_2, CO, and HC values were 487.84 g/kWh, 13.345%, 0.60%, and 98.84 ppm, respectively. The correlation (R^2) values for BTE, CO_2, BSFC, CO, and HC were 95.12%, 99.62%, 94.36%, 99.42%, and 98.08%, respectively, which depicts that R^2 values are acceptable for all responses.

Cakmak et al. [30] employed hydroxy gas (HHO) to boost the performance of LPG in 661.5 cc engine. They found that brake power was increased by 1.24%, 2.45%, and 5.04% for 1 L/min, 2L/min, and 4 L/min of hydroxy gas flow rate respectively. The BSFC was reduced by 2.92%, 5.71%, and 11.17% for 1 L/min, 2 L/min, and 4 L/min of hydroxy gas flow rate respectively. However, the BTE was increased by 3.03%, 6.15%, and 12.97% for 1 L/min, 2 L/min, and 4 L/min of hydroxy gas flow rate respectively. The CO emissions were reduced by 2.26%, 4.31%, and 8.72% for the 1 L/min, 2 L/min, and 4 L/min of hydroxy gas flow rate respectively. The HC emissions were reduced by 4.6%, 10.5%, and 21.0% for 1 L/min, 2 L/min, and 4 L/min of hydroxy gas flow rate respectively. But the NOx emissions were increased by 2.22%, 3.77%, and 6.42% for 1 L/min, 2 L/min, and 4 L/min respectively. They inferred that hydroxy gas addition in LPG had increased the burning rate along with reduction in burn duration, extended lean limit and higher thermal efficiency Moreover, the lean limit operations were extended due to increment in air to fuel ratio from 1.35 to 1.56 for hydroxy gas addition. Munahar et al. [31] used additional fuel control systems (LPG operations) along with planetary automatic transmissions in order to achieve optimum engine performance through gear shifting controls during uphill climbing. A simulation with MATLAB Simulink we used to create a control system, with objective function and constraint defined. They concluded that the designed control system can regulate the speed gear at different road tilt angle and the designed control system can be applied in real conditions.

Although a lot of research is conducted on LPG fuel due to its tendency to produce lower harmful greenhouse emissions. However, the comprehensive investigation to ascertain the impact of LPG on lubricant oil is still missing. A few numbers of scientists have tried to investigate its impact on lubricant oil, but it was only focused on LPG impact on physicochemical properties of lubricant oil. In the current study, the variation in wear particles like aluminium (Al), iron (Fe), copper (Cu) and chromium (Cr) along with variation in performance additives like calcium (Ca), zinc (Zn) and phosphorous (P) are deeply discussed for the lubricant oil operated on both gasoline and LPG subsequently. Therefore, this study intends to investigate the performance and emissions of two fuels: gasoline and LPG. The ascertained brake power, brake specific fuel consumption, brake thermal efficiency and emission content (HC, CO, CO_2, NOx) of both the fuels (gasoline and LPG) were compared. A work similar to this has already been widely studied [19,20,27,32–41]. However, this study unveils gasoline and LPG's effect on engine oil properties after complete 120 h operation. Moreover, the impact on additive depletion and contamination of lube oil by debris has also been considered. Later, the statistical concept of correlation was applied to performance and emission obtained data for inferring strength of statistical relation of variables (emission and performance) with speed. The comparison then made between two statistical approaches (Pearson and Spearman Correlation) on the basis of correlation coefficients, percentage difference and p values of all samples, and the obtained results were compared to the literature and deviations have been addressed.

2. Methodology

The arrangement of equipment used in this study is depicted in Fig. 1. The setup encompasses two fuel supplies, exhaust temperature sensor, lube oil temperature sensor, gas analyzer and dynamometer (7 inches). The SI engine used was the four-stroke single-cylinder (219 cc). Two fuels, gasoline and LPG (properties listed in Table 1) were separately utilized for the combustion process. For both the fuels, the methods employed for measuring specific fuel consumption were dissimilar. Gasoline fuel consumption was measured using a graduated cylinder (1000 mL) while for LPG, consumption was recorded using measurement weight machine (digital).

Engine throttle opening was kept at 60% during the experiment. The performance and emissions were recorded in two stages, as shown in Table 2. The performance parameters of fuels under study were recorded at each rpm using the dynamometer coupled to the driving shaft. The outputs in both cases were obtained from the interface of software (DYNOMAX 2010).

Similarly, the steady-state emissions of gasoline and LPG were recorded at each rpm. Once the fluctuation in speed become stable, the TESTO 350 gas analyzer probe was placed in the exhaust manifold for the interval of 60 s; which measured quantity in ppm for CO, NO_x, HC and in percentage by volume (%V) for CO_2. The speed was gradually increased in order to ascertain performance and emissions had characteristics. This study also investigates the impact of two fuels (gasoline and LPG) on lubricating oil. The lubricant oil available as PSO CARINET 20W-50 (physiochemical properties listed in Table 3) was utilized in the current study. First, the properties of lube oil (kinematic viscosities at 40 and 120 °C, flashpoints and total base number (TBN)) measured using American Society for Testing and Materials (ASTM) standards ahead of the onset of experimental runs (0 h), i.e., fresh oil (see Table 3).

Furthermore, the additives and concentration of metal constituents in fresh lubricant oil were noted and displayed in Table 3. Next, with gasoline in use, the oil was allowed to function for 120 complete hours, as suggested by the manufacturer. Subsequently, the oil was extracted and tested against the standards (Table 3), and the deviations were recorded. Finally, the additive depletion and emergence of foreign metallic particles (wear debris) were noted. The same stated procedure was used for the engine operating on gaseous fuel.

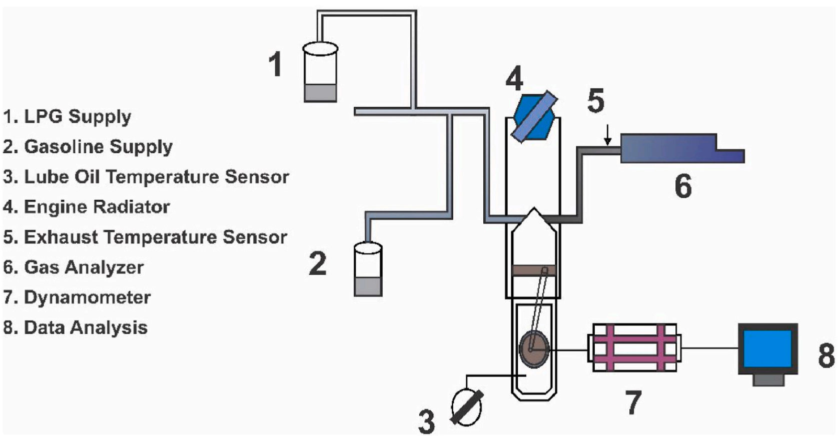

Fig. 1. Schematic diagram of the experimental setup.

Table 1
Properties of LPG and gasoline.

Properties	LPG	Gasoline
Octane Number	103	97
State	Gas	Liquid
Calorific Value (MJ/Kg)	46.1	46
Air Fuel Ratio	17.2	14.7

Table 2
Test strategy.

Quantity	First Stage	Second Stage
Speed	1800–3200 7 equal Steps	3200–3300 One go

Table 3
Physiochemical Properties, Additives and Metallic particles in fresh lube oil.

Lube oil	Total Base Number (TBN) (mg.KOH/g)	Kinematic Viscosity @40 °C (cSt)	Kinematic Viscosity @120 °C (cSt)	Flash Point (°C)	Calcium (wt. %)	Zinc (wt. %)
Standard	D974	D445	D445	D92	D6595	D6595
Values	7.80	173.21	19.45	226	0.2728	0.1453

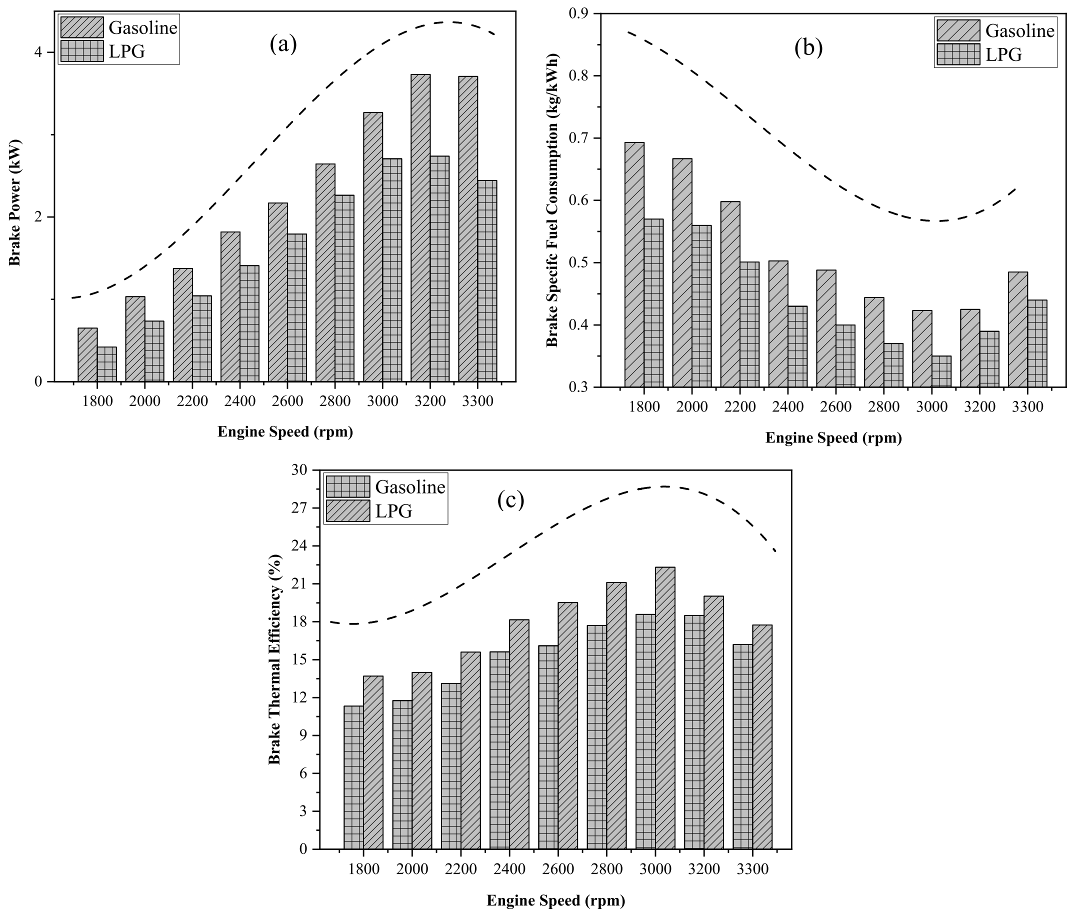

Fig. 2. The variation of; (a) Brake Power, (b) BSFC, and (c) BTE with engine speed.

3. Results and discussion

3.1. Engine performance assessment

Comparison of brake power of gasoline and LPG is noticeable in Fig. 2(a). It is discernible that gasoline surpassed LPG by producing an average 23.74% higher brake power than its competitor (gasoline). Both fuel's maximum power was observed at test rpm of 3200, with gasoline and LPG generating 3.73 kW and 2.74 kW respectively. As anticipated, the bars are exhibiting general rising-falling pattern. For both cases, incremental movement along abscissa is directly related to the movement along ordinate up to 3200 rpm. Afterwards, the parameter incurred abrupt decrease, indicated by the bowlike shape of bars. This behaviour could be accredited to higher frictional losses at increased revolutions of the power-producing shaft [42,43].

BSFC variation of an engine pertaining to two different fuels is shown in Fig. 2(b). In terms of fuel economy, engine incorporating LPG emerged unusually better than gasoline operated engine. At test speed of 2400 rpm, the parameter differed by 14.51% with gasoline and LPG showing BSFC of 0.50 kg/kWh and 0.43 kg/kWh. However, on average, LPG showed 15.13% lesser fuel consumption to its counterpart, promising better engine's efficiency due to higher volatility of gases and improved combustion process [44]. Unlike BP, a general trend is found to be with the decreasing-increasing pattern. Starting from 1800 rpm, BSFC dwindled up to an optimal speed of 3200 rpm and increased later. Generally, a similar trend upholds for almost all fuels which could be attributed to (a) augmented fuel demand due to increased frictional resistance between moving/reciprocating parts of an engine at higher speeds and (b) reduced inhaling time of the engine [20].

Engine performance for two fuels is graded by brake thermal efficiency (BTE) in Fig. 2(c). BTE is a measure of useful energy produced by an engine at the expense of unit input fuel. Once again being 14.33% more efficient, LPG proved itself as better fuel than gasoline which could be ascribed to higher average octane number [45]**.** Indicated by the curve's peak, maximum thermal efficiency for fuels under observation occurred at 3000 rpm. Generally, increased revolutions of the engine shaft are accompanied by decreased completion time of combustion. Thus, the engine demands more fuel for producing the desired output, which results in decreased BTE, indicated by a downward bent portion of the curve [46].

3.2. Environmental characteristics

Variations in HC emission of gasoline and LPG is depicted in Fig. 3(a). The declining trend represents any spark engine's

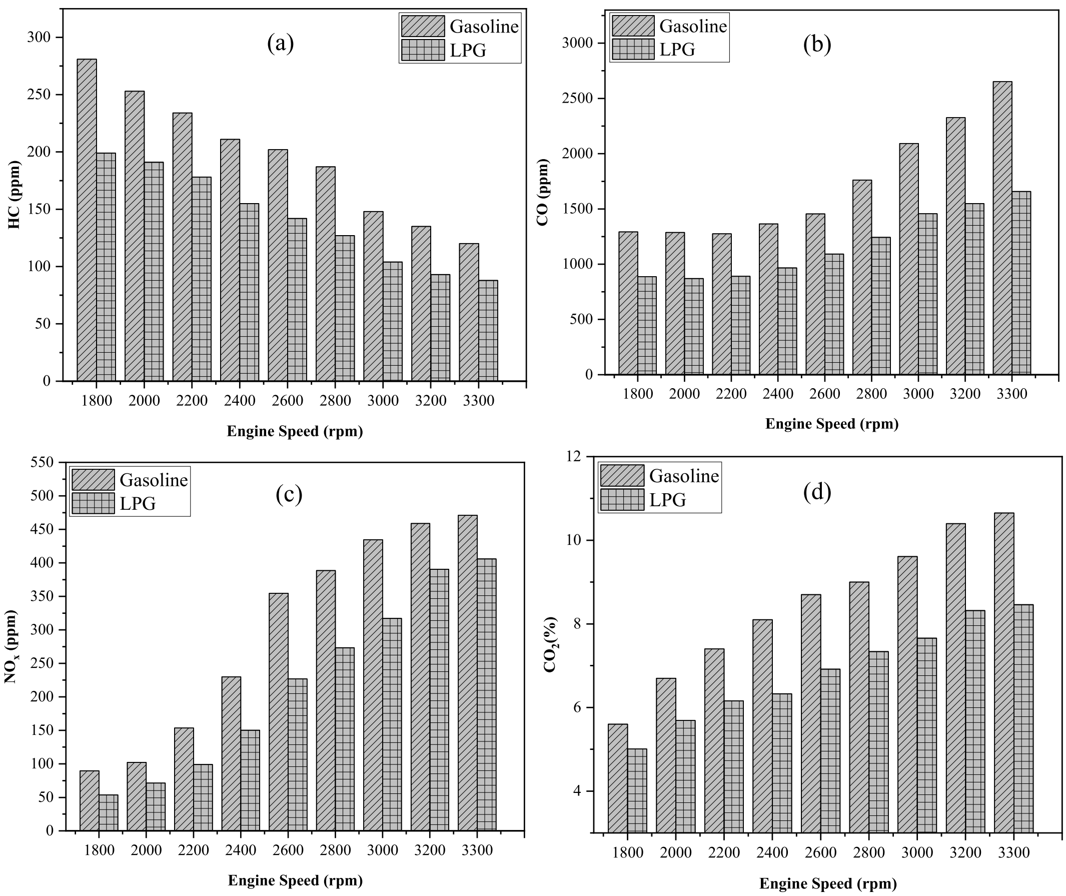

Fig. 3. The variation of; (a) HC emission, (b) CO emission, (c) NO_x emission, and (d) CO_2 emission with engine speed.

hydrocarbons emissions general behaviour when subjected to incremental speed variation. This could be explained by incomplete combustion of fuel. The maximum of 281 and 191 ppm was recorded, respectively, for gasoline and LPG at the onset of the experiment, i.e., 1800 rpm. On comparison at 2600 rpm, gasoline produced 29.70% higher HC emission content than the gaseous fuel (LPG). The lower HC emissions in case of LPG is due to higher flame propagation speed and combustion temperature of LPG [45].

Graphical plot of engine speed with CO emission of gasoline and LPG is shown in Fig. 3(b). The bars represent the overall trend of gas in mention for both fuels. From the commencement of test speeds, parameter declined up to particular rpm (2200) and later increased. As depicted, the emission of LPG is significantly lower than gasoline. Engine incurred a reduction in average value from 1723 to 1179 ppm when operated on LPG, proving gaseous fuel's effectiveness. LPG emerged better in terms of CO emission due to: (a) higher flame speed, (b) improved combustion owing to proper mixing and (c) lesser carbon content than gasoline [47,48].

The variation of Nitrogen oxides (NOx) in a speed range of 1800–3300 rpm is shown in Fig. 3(c). Average emission of NO_x with gasoline in use emerged 25.92% higher when associated with LPG. The culmination of experimental runs, i.e., 3300 rpm, recorded 471.20 and 406 ppm for liquid and gaseous fuel respectively. Emission of oxides of nitrogen is governed by (a) physical state of fuel (b) temperature in the housing of cylinder and (c) accessibility of oxygen and nitrogen [49]. Lesser consumption time and liquid state are factors accounted for higher NO_x in case of gasoline [20]. For both fuels, the general trend of NO_x emission is portrayed by dotted curve. In accordance with the literature, the curve pattern is solely rising; indicating the surge in the formation of nitrogen oxides at high speeds and elevated temperature [50].

Comparison of emission of greenhouse gas for gasoline and LPG at varying speed is shown in Fig. 3(d). Once again, LPG is declared preferable due to 18.74% less contribution to % volume emission. At 3000 rpm, the gasoline and LPG produced as 9 %volume and 7.34 %volume CO_2 emissions respectively. The most considerable variation was observed at the maximum speed of 3300 rpm. The comparative better performance of LPG is attributable to improved burning and lesser carbon to hydrogen ratio [44,45,51]. Engine speed and CO_2 emission are found to be directly related, as indicated by the curve.

3.3. *Lube oil deterioration and wear debris*

The smooth working of the engine is heavily dependent on the condition of lube oil [52]. Lube oil contains the friction between parts of an engine and guards against metal wear and corrosion. In this section, the effect of gasoline and LPG on the degradation of lube oil is considered. The deterioration of lubricating oil has been graded by the following properties: Total base number (TBN), kinematic viscosities and flash point [53]. The effect of two fuels (gasoline and LPG) on flashpoint, viscosities and TBN, after the 120 h engine running, is apparent in Fig. 4.

Flashpoint is the minimum temperature at which vapours of lubricating oil ignite, once provided with a spark. The purity of lube oil is judged based on the value of flashpoint; the higher the parameter, the higher its purity. Gasoline and LPG marked the flashpoints of 194 °C and 214 °C, respectively, on the plot's ordinate shown in Fig. 4. The lubrication in an engine is severely affected by variations in kinematic viscosity of lube oil. Factors like the formation of oxidation products, the presence of water and the liquefication of fuel are most noteworthy in this regard. The efficient working of engine demands viscosity of oil to be high. At a temperature of 40 °C, the viscosities of lubricant oil in case of gasoline (138.70 cSt) and LPG (156.40 cSt) varied by 12.76%, with the lubricant oil in case of LPG being more viscous. Similarly, gaged at 100 °C, liquid and gaseous fuel exhibited viscosities of 14.73 and 16.90 cSt, latter still being ahead of the former. The gasoline mixed with the lubricant more as compared to LPG which dilute the lubricant oil. That's why the lubricant oil ran on gasoline possess lower viscosity than the lubricant oil that ran on LPG [1].

The liquid state of gasoline contributed to the flashpoint and kinematic viscosities diminution due to fuel dilution [42,50,54]. The alkalinity of oil is measure by TBN. The low value is a measure of increased corrosion, and poor performance and reverse is the case for high value. As indicated, TBN for gasoline is 5.14% lower than the gaseous fuel. The deviation of properties in mention from fresh oil is

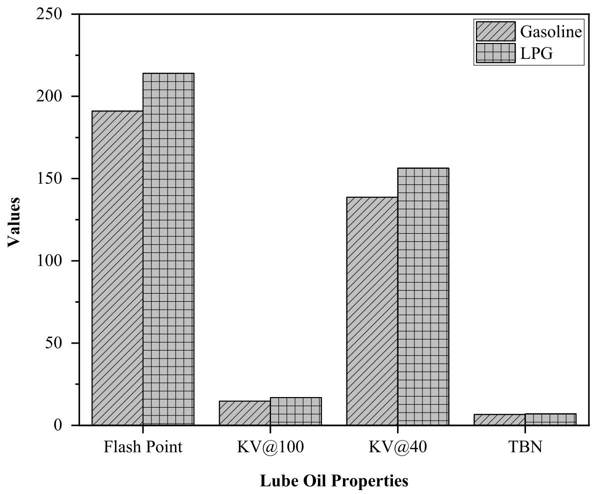

Fig. 4. Comparison of properties of lube oil.

also considered. Flashpoint decreased by 16.23 and 6.14% for gasoline and LPG respectively. Similarly, kinematic viscosities decreased by 24.67% and 13.11% at 40° while 19.72% and 6.65% at 120° for liquid and gaseous fuels. For gasoline and LPG, TBN declined by 14.74% and 10.13% in contradistinction to fresh oil.

Oxidation products formation is lethal for lube oil as they form acids and resins. The oxidation process is intensified in the occurrence of foreign metallic particles, which could deteriorate oil unprecedently and, therefore, be considered [39]. Fig. 5 shows comparison of Fe, Cu, Cr and Al concentration in lube oil after 120 h engine operation for gasoline and LPG. Iron (Fe) showed the highest concentration for gasoline (35 ppm) and LPG (27 ppm).

Most of the mechanical components inside automotives are mainly made up of iron-based alloys. The lubricant oil is considered as blood in the engine as it flows inside the channels of engine mainly for cooling and removal of wear debris [55]. Therefore, the wear and tear of crankshafts, cylinder valves, bearings, piston rings and other auxiliaries are primarily accountable for presence of iron (Fe) particle inside lubricant oil. The piston is primarily made up of aluminium (Al), therefore the concentration of aluminium particles in lubricant oil depicts wear in piston. The intermediate layers of engine bearing are made up of copper alloys and presence of copper in lubricant oil specifies the wear among these layers [56]. The journal bearing and jackets are the prime sources of copper in the lubricant oil. The dormant source of chromium (Cr) particle in lubricant oil as wear debris are cylinder liners, piston rings and crankshafts [57]. The ASTM D-6595 standard was opted to ascertain the wear debris in lubricant oil through a spectrophotometer manufactured by SpectrOil.

The prompt visual comparison reveals that gasoline caused a considerably higher occurrence of all suspended particles compared to pure fuel. However, LPG exhibited 22.86%, 50%, 45.45%, and 37.50% reduced concentration of Fe, Cu, Cr and Al, respectively compared to gasoline. Compared with non-deteriorated oil, gasoline showed 35%, 4%, 22%, and 24% increase in Fe, Cr, Cu, and Al concentrations. Similarly, LPG behaved way better with 27%, 2%, 12%, and 15% rise in Fe, Cr, Cu, and Al concentration in contrast to fresh oil. The lower wear debris in lubricant oil in case of LPG can be explained by less fuel dilution in case of gaseous fuel. The higher wear rate is result of higher combustion temperature inside engine cylinder [37]. The higher NOx in case of gasoline depicts higher combustion temperature inside cylinder. It turned to be the significant reason for higher wear debris mixed in lubricant oil in case of gasoline.

Lube oil composition is a blend of base lube oil and additives, with each performing assigned function. The additives like calcium

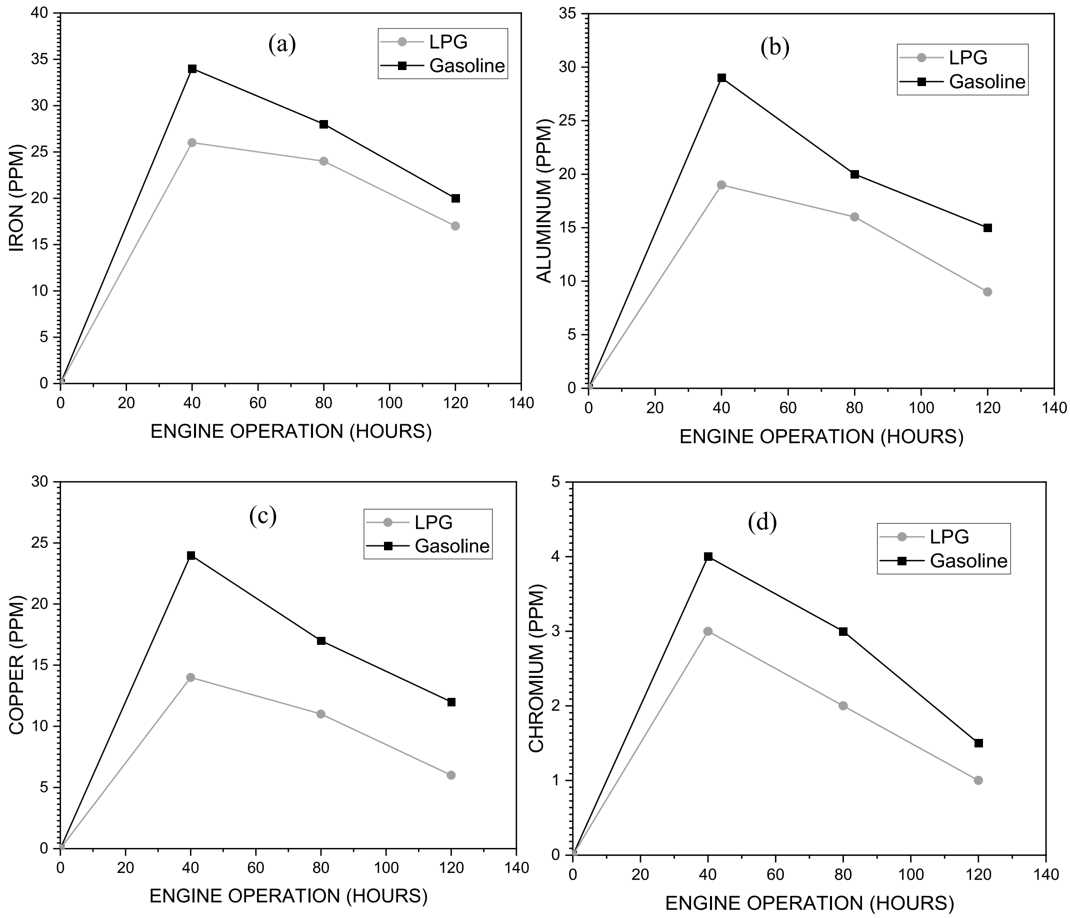

Fig. 5. Variations in (a) Fe, (b) Al, (c) Cu, and (d) Cr with respect to engine running hours.

(Ca), zinc (Zn), and phosphorous (P), act as a temperature controller and protect high-temperature deterioration. The additives addition significantly improves the lubrication performance of the oil. During engine operation, the chemical structure of fuel remains less affected while the significant change is the depletion of additives [58]. The depletion deteriorates lube oil and thus affect engine performance. The comparison of depletion of additives (Ca, Zn, P) after 120 h of engine operation fuelled with gasoline and LPG separately, is shown in Fig. 6. LPG was found to have a comparatively lower additive depletion rate (16.80% for Ca, 14.78% for zinc and 4.42% for P) compared to liquid fuel. However, gasoline and LPG showed a decline of 19.72 and 6.65% for Ca in comparison with fresh oil. Similarly, LPG proves to be more efficient with a 6.47% increase in phosphorous depletion compared to gasoline (18.51%), with fresh oil in use.

3.4. Estimation of strength of relation

In this section, the relation of performance and emission parameters with speed is validated using the basic statistics concept of correlation. It is a technique used to assess the strength of the connection between all the possible combination of variables under consideration. At present, two methods are well known: Pearson and Spearman correlation [59]. Contingent on detailed data being linear or monotonic; the selection must be made [60]. Pearson correlation evaluates the linear relationship between two continuous variables. However, Spearman correlation evaluates the monotonic relationship with ranked variables and non-parametric nature of data. The Spearman correlation coefficient is based on the ranked values for each variable rather than the raw data. Pearson correlation indicates the presence or absence of correlation between any two variables and determines the exact extent or degree to which they are correlated. Pearson correlation is preferred for linear relationships, quantitative variables, normally distributed data and data with no outliers. A novel approach for this identification is through scatter plots. Fig. 7(a–g) shows the performance and emission scatter plots of gasoline and LPG with engine speed (rpm). The data points in all graphs are less haphazard, which is a rational hint of adopting the Pearson correlation method [61].

The output of this process is presented in the form of correlation coefficients (r and p-value). The numerical value of R has a range of [−1,1]. Negative extreme (−1) indicates a perfect negative correlation, while positive extreme (+1) designates a perfect positive correlation. The zero indicates no association between measured variables [62]. The p-value is a litmus test for assessment of the significance of relationships [63]. A value greater than 0.05 for p makes correlation sparse, and the term could be omitted.

Various software packages are available for statistical calculations. Here, MINITAB 17 has been used. The results of the correlation of engine speed (RPM) with all variables are itemized in Table 4. Moreover, Table 4 compares the correlation strength and percentage difference in case of both Pearson and Spearman correlation approach. The alphabets (G) and (L) with performance (BP, BSFC, and BTE) and emission parameters (CO, CO_2, HC, and NOx) represent gasoline and LPG, respectively. Brake power, CO_2 and NOx of both the fuels (gasoline and LPG) showed strong positive dependence on the speed of the engine. However, BTE exhibits weak positive correlation with engine speed in case of both gasoline and LPG. On the other side, HC emission exhibits strong negative dependence on engine speed. While, BSFC exhibits weak negative correlation with engine speed. The percentage difference indicates the variation from linear behaviour. The higher percentage difference in case of BTE and BSFC mainly because of bent shaped curve when data plotted against engine speeds. The lowest percentage difference in case of NOx, HC, CO_2 and BP is mainly because of linear behaviour of data when plotted against engine speed.

The anomaly in data points at the top right corner of Fig. 7 (a) is the reason for the deviation of R value from an ideal case. Similarly, speed entangled itself to BTE of gasoline and LPG in slightly weak positive correlation as compared to BP. For fuels under consideration, the speed showed considerable positive strength of relation for CO, CO_2 and NO_x. HC emission distinguished itself from all emissions by exhibiting a strong negative correlation for LPG and gasoline. The p-value of all samples turned out less than 0.05; indicating speed has a statistically significant effect on the spark ignition (SI) engine's performance and emission.

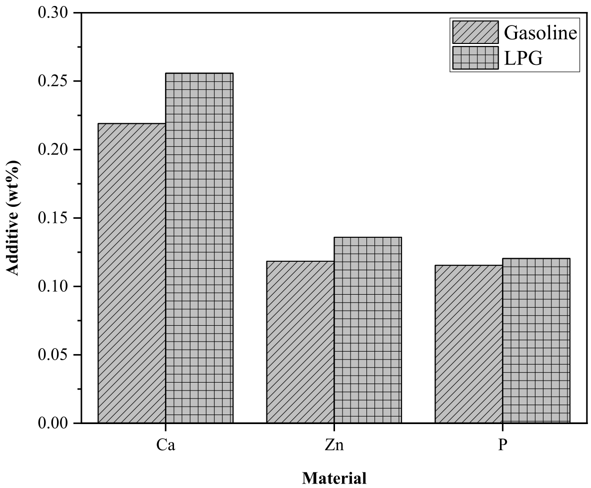

Fig. 6. Comparison of additive depletion.

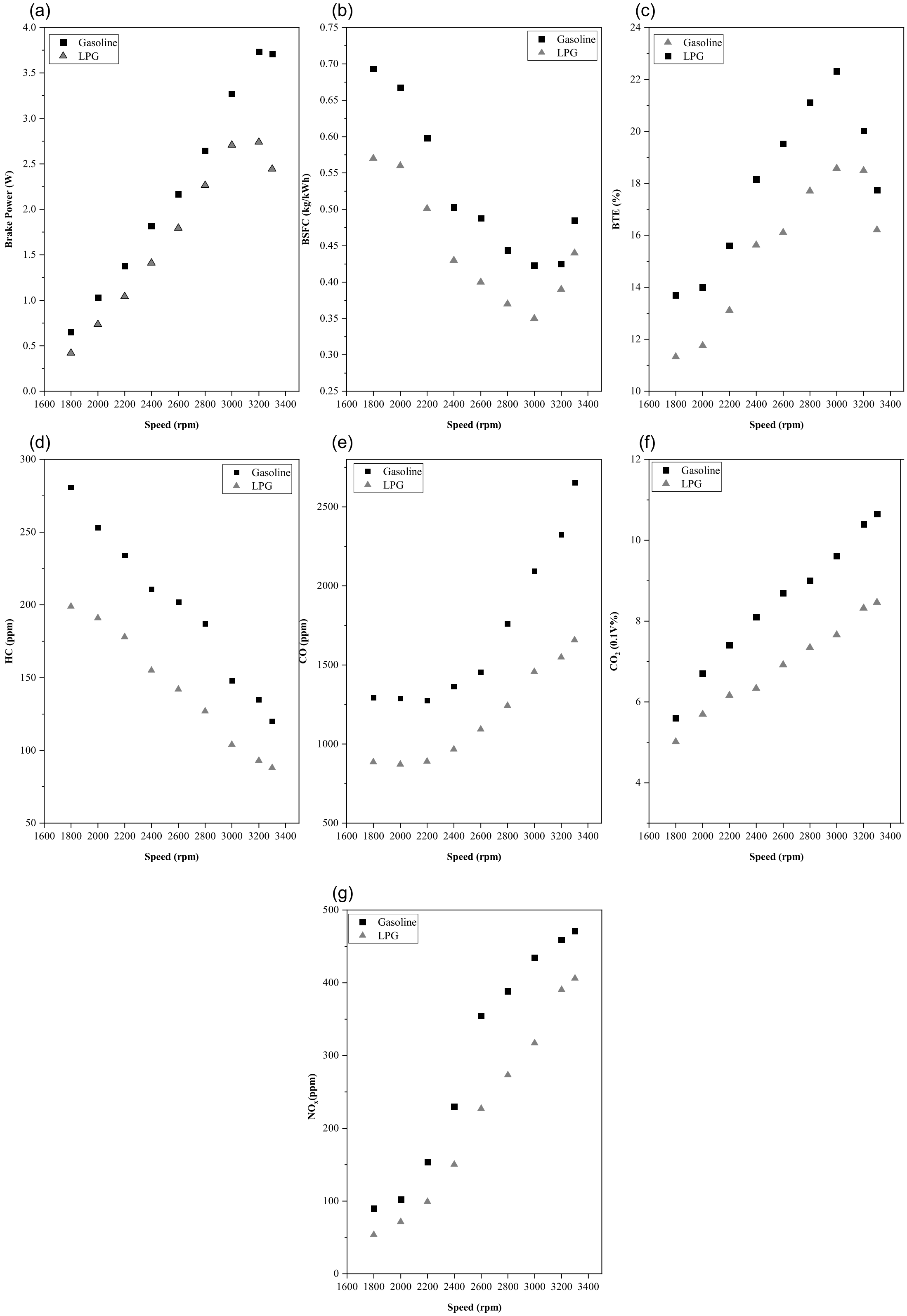

Fig. 7. Scatter plots of; (a) BP, (b) BSFC, (c) BTE, (d) HC, (e) CO, (f) CO_2, and (g) NOx with engine speed.

Table 4
Correlation coefficients.

Variable 1	Variable 2	Pearson correlation			Spearman correlation		
		R-value	P- value	Percentage difference	R-value	P- value	Percentage difference
RPM	BP (G)	0.9963	0.0000000097	0.37	0.9833	0.0000019	1.67
RPM	BP (L)	0.9721	0.000015	2.79	0.95	0.000087	5
RPM	BTE (G)	0.8920	0.00122	10.8	0.9535	0.000068	4.65
RPM	BTE (L)	0.7819	0.01279	21.81	0.7011	0.0035	29.89
RPM	BSFC (G)	−0.8951	0.0038	10.49	−0.9250	0.0028	7.5
RPM	BSFC (L)	−0.8130	0.0043	18.7	−0.7023	0.0031	29.77
RPM	HC (G)	−0.9937	0.00041	0.63	−0.9987	0.00053	0.13
RPM	HC (L)	−0.9962	0.00001	0.38	−0.9991	0.00008	0.09
RPM	CO (G)	0.9226	0.000392744	7.74	−0.9333	0.0002359	6.67
RPM	CO (L)	0.9597	0.000041	4.03	−0.9833	0.0001169	1.67
RPM	CO2 (G)	0.9931	0.000000089	0.69	0.9989	0.000013	0.11
RPM	CO2 (L)	0.9959	0.000000013	0.41	0.9994	0.000007	0.06
RPM	NOx (G)	0.9802	0.000691	1.98	0.9786	0.000314	2.14
RPM	NOx (L)	0.9915	0.000354	0.85	0.9975	0.000143	0.25

4. Conclusions

The present discussion incorporated the detailed assessment of gasoline and LPG in the following domains: performance, emission and lube oil degradation. The outcomes of the study are:

- Gasoline proved valuable only in terms of brake power with 23.74% more brake power production than LPG.
- Gasoline emerged inferior to LPG in terms of BSFC and BTE. It consumed 15.13% more fuel and showed 23.74% reduced efficiency in comparison with LPG.
- LPG appeared preferable in terms of sustainable and clean environment due to 27.89 and 31.54% lower HC and CO emissions respectively than gasoline. This shows that LPG has the potential to be employed in lieu of gasoline in SI engines.
- The main issue with alternative to gasoline is the higher production of CO_2 and NOx due to higher combustion temperature inside cylinder. But LPG has solved this main problem by producing 18.74, and 25.92% lower CO_2, NOx emissions respectively as compared to gasoline.
- Flash point, kinematic viscosities and TBN of lube oil were favourable for LPG.
- LPG showed the reduced concentration of 22.86, 50, 45.45 and 37.50% for Fe, Cr, Cu and Al.
- The depletion rate of Ca, Zn and P in lubricant oil for gasoline was 16.80, 14.78 and 4.42% higher than LPG.
- Performance parameters (BP, BTE), CO, CO_2, and NOx emission returned a positive value of the Pearson correlation coefficient.
- BSFC and HC emission decreased with increasing the engine speed; demonstrated negative correlation.
- The higher wear debris and NOx emission clearly depicts higher combustion temperature in case of gasoline.

In the view of the above discussion and conclusions, it could be apprehended that LPG imparted lesser deterioration to lubricating oil in contrast to gasoline. The engine incorporating LPG increase the life cycle time of lube oil, consequently protecting the serene of earth from waste lube oil disposals. Moreover, the lower production of greenhouse gases in case of LPG despite being more efficient fuel make it more attractive fuel. The depicted attributes in terms of prolonged lubricant lifecycle, reduced hazardous emission and efficient fuel combustion awarded LPG as affordable and clean source of energy for climate protection. Thus, the use of LPG in spark ignition proved valuable and advantageous for a sustainable environment and in compliance with sustainable development goals set by United Nations for 2030. In future, LPG should run with hydroxy gas in order to be effective in higher power applications.

Author statement

Muhammad Usman: Conceptualization, Methodology. Muhammad Ali Ijaz Malik: Experimentation, Data curation. Muhammad Kashif Jamil: Writing- Original draft preparation. Qasim Ali Ranjha: Visualization, Investigation. Waseem Arif: Supervision. Sajjad Miran: Writing- Reviewing and Editing. Saad Siddiqui: Software, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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