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Analysis of the Impact of Propanol-Gasoline Blends on Lubricant Oil Degradation and Spark-Ignition Engine Characteristics

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Abstract: Alcoholic fuels have recently come to light as a sustainable source for powering today's vehicles. Various studies have investigated the effects of alcoholic fuels on engine efficiency and emission characteristics. However, scarce literature is available for their effects on lubricant. Therefore, propanol-gasoline fuel mixtures, with concentrations of 9% (P9) and 18% (P18) propanol, were made to compare their engine characteristics and lubricating oil condition with that of pure gasoline (0 percent propanol (P0)). To determine the rate of deterioration, the characteristics of the lubricating oil were evaluated after 100 h of engine operation, as suggested by the manufacturer. When compared with unused lube oil, P18 showed reductions in flash point temperature and kinematic viscosity of 14% and 36%, respectively, at 100 °C. For P18, which contains Fe (27 PPM), Al (11 PPM), and Cu (14 PPM), the highest wear element concentrations in the lubricating oil were found. The moisture in the degraded oil was well within the allowable limit for the three fuel mixtures. With the increase in propanol percentage in the propanol-gasoline blend, the engine performance was increased. Compared to P9 and P0, P18 had the partially unburned emissions.

Keywords: propanol; metal particles; lubricant degradation; spark ignition engine; coefficient of variance



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1. Introduction

The utilization of fossil fuels in various fields has increased sharply in the recent decade. The increase in number of internal combustion engines for both transport and power generation has decreased fossil fuel reserves, and increased environmental pollution. Alternative fuels like hydrogen, natural and liquefied petroleum gas, and alcoholic fuels have been used to control the environment and the rate of sudden decline of these fuels. Propanol and other alcoholic fuels are used in spark-ignition engines (SI), both separately and in a blended form, to address this issue. Research studies have shown that, at low blending ratios, gasoline can be utilized in SI engines without modification because its thermo-physical characteristics are closely related to those of propanol [1]. Moreover, a lot of work has already been done on methanol-blended fuels [2] and ethanol-blended fuels [3], [4], but propanol was of interest due to the lack of its usage to date. To reduce emissions and improve performance, manufacturers must ensure low oil use. Using the right lubricant is one way to reduce friction between the dynamic parts of the system [5]. The lubricating system is made to keep its parts moving easily, minimize frictional losses, and get rid of unwanted particles [6]. The piston-cylinder sliding pair is responsible for

40 to 50% of an engine's frictional losses [7]. Lubricating oil deteriorates over time due to contamination. Potential impurities that can cause oil deterioration include dust particles, metal fragments, water content, metal oxides, acid production, and residual gases [8]. The impact of regenerative engine oil on emissions and engine performance was examined by the researchers. Along with improved brake power and engine torque, emissions were decreased when evaluated with used oil [9]. Moreover, an extensive study is available about the refining and re-deployment of the waste lube oil regarding SI engines. The novel study explained the impact of various conditions of lubricating oil on engine characteristics [10]. In another related study, it was found that the moisture level in the lubrication oil was higher for ethanol at 85% concentration in gasoline than simple gasoline in SI engines [11]. There is a research gap in the literature about the effects of biofuels on the deterioration of engine oil. Propanol-gasoline mixtures and pure gasoline have different properties and operating temperatures. The physical and chemical properties of lubricating oil have a direct impact on the performance and lifespan of internal combustion engines. As a result, the fuel used to run the engine may have an impact on the condition of the oil. Over time, as the engine operates, metal particles from various components of the engine appear in the lubricating oil. Additionally, iron is found in the crankshaft, camshaft, gears, piston rings, cylinder liners, and pistons. Aluminum exists due to the wear and tear of rod and piston bearings. Sources of copper include the copper alloys used in clutch plates, main or rod bearings, and water and oil coolers. Therefore, analysis is necessary to examine the impacts of an alcoholic fuel (propanol) on the conditions of the lubricating oil, the efficiency of the SI engine, and emission levels.

The usage of a propanol-gasoline fuel blend reduces vehicle engine pollution, particularly carbon monoxide and hydrocarbon emissions, by 10.87% and 14.18%, respectively [12]. Propanol was added to unleaded gasoline in amounts of 3, 9, 12, and 18 percent by volume. The alternative fuel resulted in a reduction in CO and HC emissions, whereas NO_x and CO₂ emissions with blended fuels increased [13].

This study describes the induction of three propanol and gasoline fuel blends i.e., P0, P9, and P18 into a spark-ignition (SI) engine. With the assessment at 100 h of engine running, as suggested by the manufacturer, a comprehensive evaluation of lubricating oil characteristics is done for all the blends compared with fresh engine oil. The performance characteristics with emission gases were observed at a defined engine rpm range.

2. Methodology

This study used a 163 cc and 4-stroke spark-ignition engine. The engine was operated at various speeds, ranging between 1700 to 3800 rpm, with a constant gap of 300 rpm. Then, the parameters were evaluated after running it with unblended gasoline (P0) and propanol-gasoline mixtures, i.e., P9 and P18, as shown schematically in Figure 1. Moreover, up to 20% alcohol concentration in the blended fuel mixture allows the engine to run without any kind of modifications, for C1 to C4 chains of alcoholic fuels. Thus, two mixtures were chosen, while staying within the limits, at equal intervals that were 9% and 18% propanol-gasoline blend. The lubricant testing was carried out using SAE 20 W-40 engine oil (manufactured by Atlas Honda). The samples of lube oil were taken after 100 h of engine running, as suggested by the manufacturer, for each blended fuel in an air-tight glass jar and tested within 48 h of time using ASTM standards. Various lube oil properties for the blends i.e., flash point temperature, total base number (TBN), metal particles, and kinematic viscosity were investigated. The specific information of the engine oil used was SM according to API. The physiochemical properties of the lube oil were evaluated against the properties of the fresh oil (see Table 1) to study the deterioration of the lube oil. Moreover, various engine parameters (torque, thermal efficiency, and brake power) and exhaust emissions (HC, CO, NO_x, and CO₂), in units of percent by volume, were also analyzed for each of the fuel combinations.

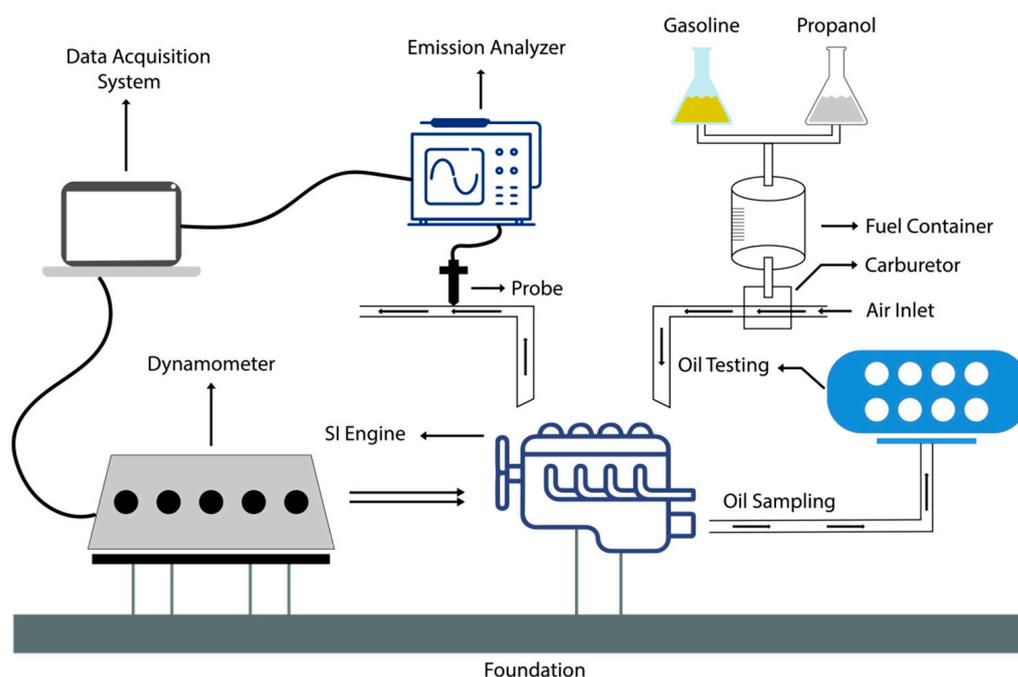


Figure 1. Representation of the experimental setup.

Table 1. Lubricant oil properties.

Parameters	Test Standards	Units	Fresh Oil (20 W-40)
Kinematic viscosity at 100 °C	ASTM D445	cSt	17.6
Kinematic viscosity at 40 °C	ASTM D445	cSt	159.1
TBN	ASTM D4739	mg KOH/g	8.7
Flash temperature	ASTM D92	°C	162

The fuel and air from the intake valve entered the carburetor, which was mixed and delivered to the cylinder of the engine for combustion. A water brake dynamometer (kart 7 inch, manufactured by Dynamite) was used to measure brake torque. The DYNO-MAX 2010 software was employed to collect the performance characteristics of the engine. The software functioned as a data-gathering system. Pakistan State Oil (PSO) provided the gasoline and Sigma-Aldrich provided the propanol (chemical composition 1-propanol (C_3H_8O)) for the experiment (see Table 2). In a magnetic stirrer, two propanol-gasoline mixtures were made with 9% and 18% propanol by concentration. Using the same initial range at specific intervals of the engine speeds and measuring the reduction in fuel with respect to time yielded the fuel consumption. A TESTO 350 exhaust gas analyzer was employed to calculate emissions through engine exhaust. In addition, the performance parameters and the emissions were taken at the average time, i.e., at 50 h of engine running.

Table 2. Properties of fuel adopted for the experiment.

Property of Fuel	Units	Test Methods	Gasoline	Propanol
Calorific Value	MJ/kg	ASTM D240	45.0	33.6
Density	kg/m ³	ASTM D4052	748	803
RON	-	ASTM D2699	95	118
Oxygen Content	% By mass	ASTM D5622	0	27.6

Before starting the experimentation phase, all the seals of the engine were checked for any leakages. All the filters were reintegrated to supply the air and oil in adequate amounts. The accurate values from the dynamometer were ascertained by carefully checking the drain valves and water hoses. Furthermore, for every engine speed value (RPM), the measurement of exhaust gases, in units of percent by volume, was carried out by placing the probe of the exhaust gas analyzer into the exhaust gas pipe for one minute.

3. Results and Discussion

Using propanol-gasoline blended fuel in the SI engine, the lubricant oil deteriorated more quickly. Moreover, it yielded better characteristics of engine performance. Furthermore, HC and CO emissions reduced comprehensively, whereas NO_x and CO₂ emissions increased with blended fuels. A similar behavior was observed for butanol as well [14].

3.1. Assessment of Lubricating Oil Condition

Amongst the essential variables, one variable responsible for determining the efficacy of lubricant oil in internal-combustion (IC) engines is its kinematic viscosity. Processes such as polymerization, sludge formation, oxidation, light hydrocarbon fraction, and boiling at high temperatures can all cause it to vary. The cracking of lubricant, dilution of fuel, shearing of the viscosity index (VI) improvers, and removing the insoluble oxides, on the other hand, are the leading causes of decreased engine oil viscosity. The change in viscosity is determined by the dominance of one of the components. The kinematic viscosity of the engine oil was evaluated for P0, P9, and P18 at 40 °C and 100 °C per 100 h of engine operation. At 40 °C, the kinematic viscosity of P0, P9, and P18 was reduced by 16.3%, 36.2%, and 31.2%, respectively, in contrast to pure lube oil. The kinematic viscosity reduction at 100 °C was 23.1%, 41.9%, and 36.4% for P0, P9, and P18, respectively. The impact of a gasoline-methanol blend on lubricating oil shows the same pattern regarding kinematic viscosity changes [15]. From P0 through P18, there was an increasing trend in kinematic viscosity. Because of fuel dilution for fuel blends, propanol was present in the lubricating oil, which aided the oxidation process [3,11]. Furthermore, as viscosity index (VI) improvers degrade with engine use, the kinematic viscosity of lubricating oil drops for all blended fuels [16]. Moreover, a study is available regarding the assessment of lube oil with respect to various octane-number fuels [17].

The alkali content in lubricating oil that corresponds to acid generation and suppressing its effect is the total base number (TBN). It was measured after 100 h of engine operation. Acid production increases corrosion and oxidation, and the TBN value declines over time. TBN depicted a decrease for all fuels, which can be seen in Figure 2. Nevertheless, P18 had the most negligible alkaline levels in the lubricating oil, followed by P9 and P0. In contrast to fresh lubricating oil, TBN decreased by 14.5%, 22.5%, and 29.9% for P0, P9, and P18, respectively. The availability of oxygen and the elevated combustion temperature of the P18 blend can explain this, both of which favor acid production [18]. In the lubricant quality inspection, the flash point test has always been required. It may detect fuel dilution, thermal degradation, incorrect or mixed oil, and contaminations. Figure 2 shows how the flash point of the base oil has changed over time per 100 h of engine operation. After completing the prescribed engine operating hours, the flash point temperatures for P0, P9, and P18 were 127.3 °C, 139.3 °C, and 142.1 °C, respectively. The significant increase of flash temperature from P0 to P18 can be ascribed to the dilution of the fuel, and this was also discovered in the latest investigation into the effects of a gasoline-methanol blend's flash point temperature on lubricant oil [15]. As a result, the flash point temperature of the P0 engine oil was reduced by 9.42% and 11.62%, compared with P9 and P18, sequentially. The increase in combustion temperature for the fuel blends was manifested in combustion of light hydrocarbons and the retention of hefty components in degraded engine oil [19]. The moisture content in lube oil is terrible for engine life and functionality and can produce rust, oxidation, and metal degradation in thermal systems. Water mixing into the oil is most commonly caused by the precipitation of water content in cold starting situations

and combustion. The water content analysis for P18 fuel found a maximum of 0.015% (see Figure 2). However, water content less than 0.1% did not cause issues [20].

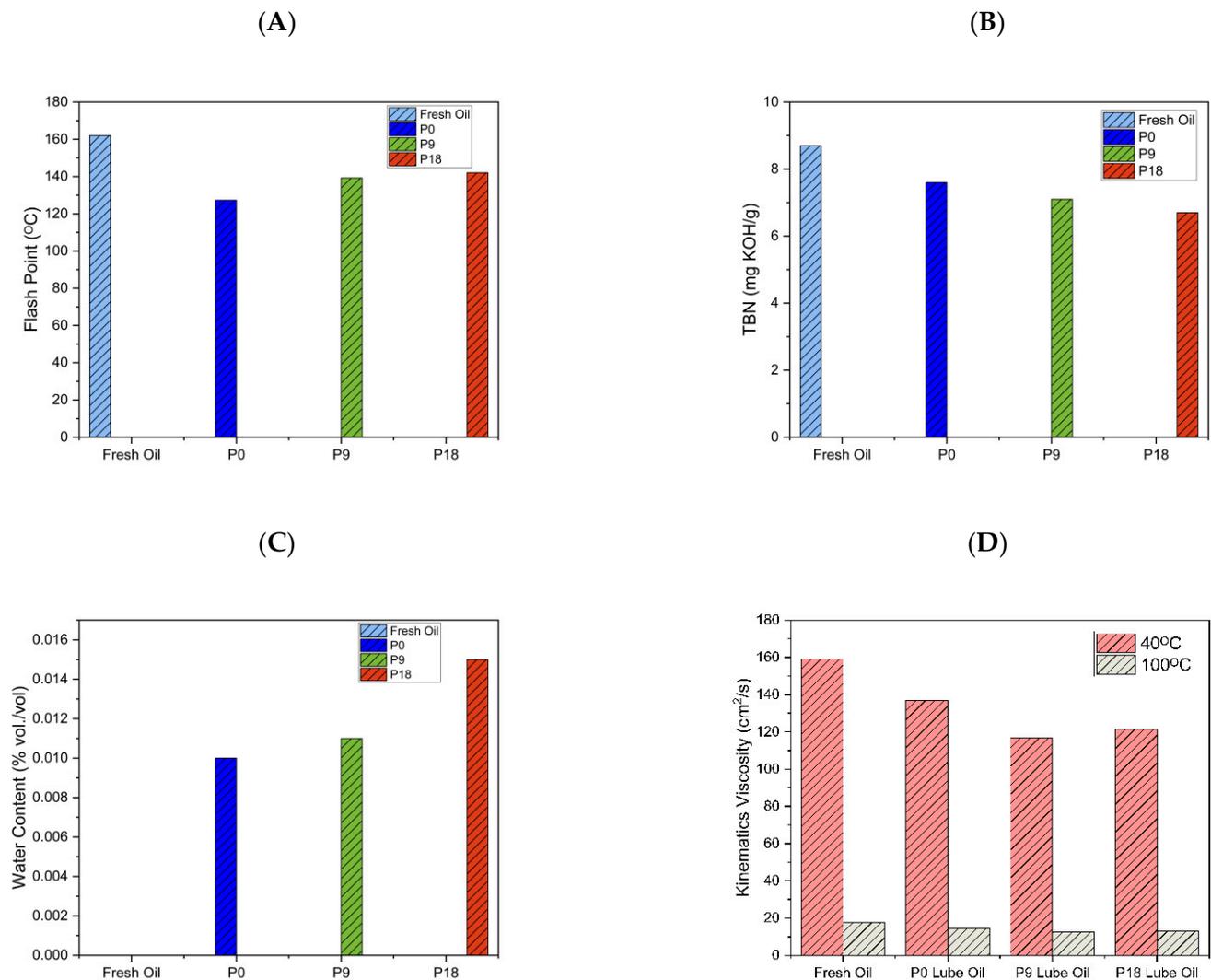


Figure 2. (A–D) Comparison of kinematic viscosity, TBN, flash point, and water content for the lubricant oils.

Wear estimation is among the essential factors in lubrication trials for estimating the state and metallic degradation of the engine under testing. Metal particles are formed by the frictional attrition between moving parts, and quantitative examination offers statistics on the pace of erosion, contamination, deterioration of oil, and origin of metallic materials [21]. As indicated in Figure 3, copper (Cu), aluminum (Al) and iron (Fe) are the most prevalent metal elements in the wear assessment of lubricating oils in SI engines. Cylinder liners, piston rings, gears, crankshafts, connecting rods, and camshafts are all sources of iron [22]. For P0, P9, and P18, an average of 22 PPM, 24 PPM, and 27 PPM particles of iron were detected, respectively. Usually, aluminum presence in lubricant oils could be attributed to the deterioration of the rod or piston bearing. For P0, P9, and P18, the Al particle concentrations were 8 PPM, 9 PPM, and 11 PPM, respectively. Blended fuels resulted in a higher engine wear rate in measures of Fe and Al due to the elevated temperatures in the combustor, and lube oil oxidation [23]. The presence of copper in the lubricant could be attributable to alloys of copper employed in the production of oil coolers, main or rod bearings, and water coolers (due to the event of any leak). The maximum copper particles were formed by P18 (14 PPM), followed by P9 (9 PPM), and then P0 (6 PPM) among the

fuel blends. Oxidation and increased engine wear are associated with oxygen in propanol molecules and acidic impurities. Compared to P0 and P9, the P18 fuel had much more metal deterioration.

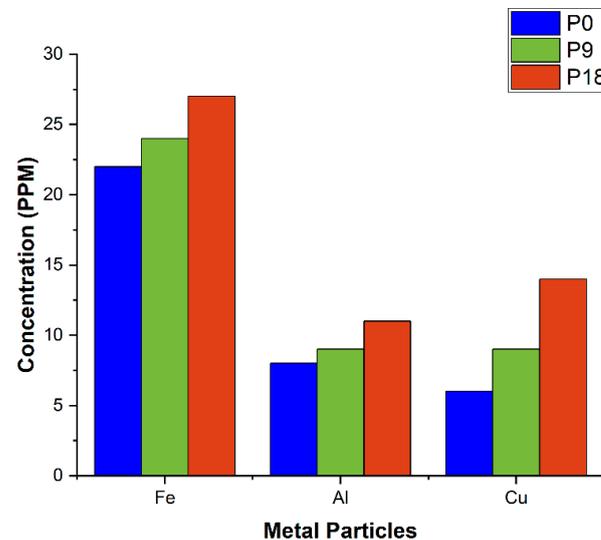
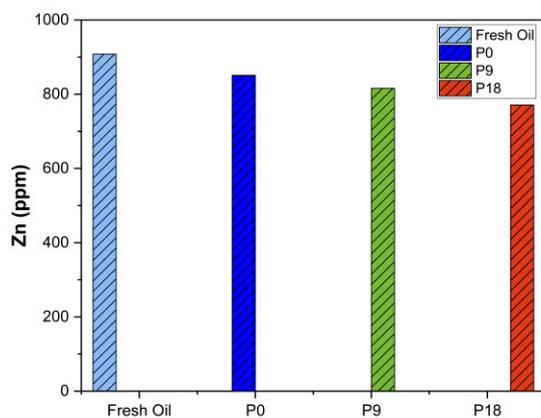


Figure 3. Metal particles suspension in lubricant oil for test fuels.

Added elements are utilized in lube oil to keep its properties stable throughout the operation of the engine. The principal added elements are calcium (Ca) and zinc (Zn), and its quantitative research method explains their successful use in lube oil. Due to the high degree of oxidation in its lubricating oil, a decline in Ca (15%) and Zn (18%) was seen in the case of P18 fuel; this phenomenon can be seen in Figure 4. These additions in the lubricant prevent corrosion growth on the outside of engine components. Calcium works as a lubricant cleanser and is an alkaline resource to prevent acid production. The highest proportions of Ca (15%) were consumed for the P18 blend after 100 h of the engine running, preceded by P0 and P9 (see Figure 4.). In a blended fuel engine, increased temperature and oxygen increases the rate of oxidation and the acidic response in the engine oil, resulting in a more significant decline in Ca levels. For the same blend, the decrease in Ca additions for P18 correlates to a decrease in TBN, as shown in Figure 2. In the case of P18, the effect of greater temperature and ash production is validated by a rise in kinematic viscosity and a reduction in Ca additives, as shown in Figure 2.

(A)



(B)

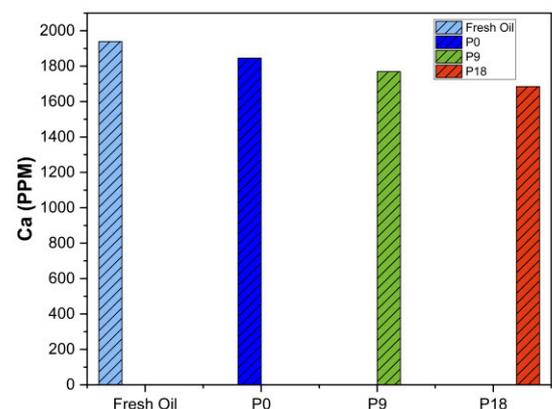


Figure 4. (A,B) Comparison of zinc and calcium for various lubricant oils.

3.2. Impact on Engine Performance

As evident from Figure 5A–C, the engine torque increases with the rise in engine speeds (RPM) for all the fuel blends, i.e., P0, P9, and P18. Thus, adding propanol to gasoline enhances the engine torque and the maximum values were noticed at 3200 rpm for every tested fuel mixture. For P9 and P18, an increase of 10.95% and 22.61% was observed respectively, when matched with unblended gasoline. This is because alcoholic liquids have a large heat of vaporization [24]. Due to the high latent heat of vaporization at the intake manifold, the temperature drop of the charge takes place. Furthermore, in the combustion chamber, it occurs due to evaporation. As a result, the high charge density and increased fuel consumption yielded higher engine torque [25]. Because the brake power also depends upon the torque and the engine speed, a similar trend was followed in the case of brake power. Propanol contains about 27.6% of oxygen by mass. When this oxygen is mixed in the gasoline, it produces a lean mixture that helps in combustion [26].

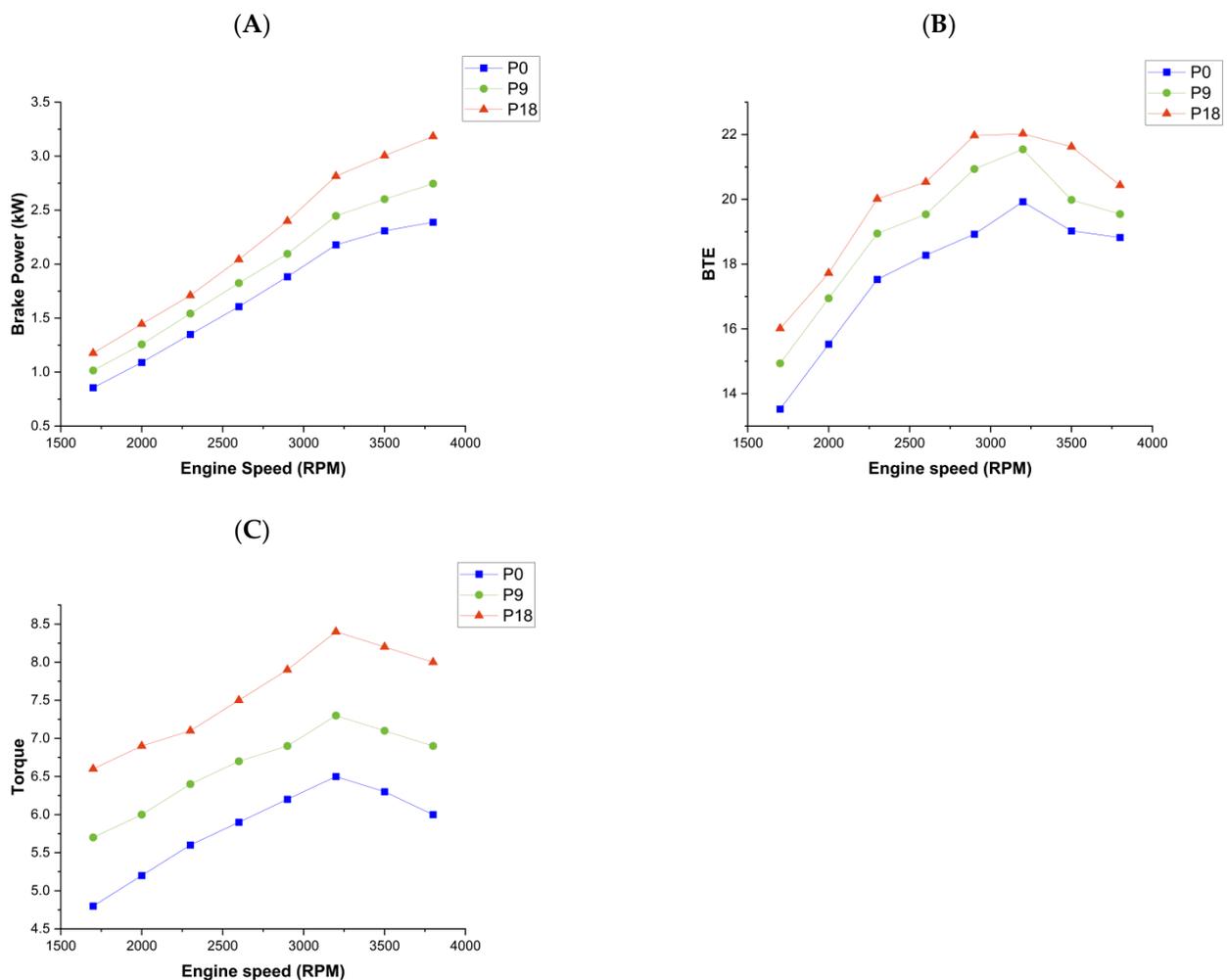


Figure 5. (A–C) Changes in Brake power, BTE, and torque for test fuels.

The relationship of thermal efficiency with the varying speeds of the engine (RPM) is shown in Figure 5A–C. It shows the increase in the thermal efficiency until 3200 rpm; after that it reduces for every tested fuel mixture. At low engine speeds, the efficiency reduced because of the heat loss to the engine cylinder, thus reducing the mechanical energy. Additionally, the mechanical output of the engine reduced at higher engine speeds because of the frictional losses that reduced fuel efficiency. For P9 and P18, the maximum increase in the thermal efficiency was noticed at 2900 rpm and 1700 rpm, i.e., 10.6% and 18.4%, respectively, when compared with gasoline. The approximate increase in the thermal

efficiency was about 7.8% and 13.5% for P9 and P18, respectively, compared with gasoline. Due to the high latent heat of vaporization of the fuel, the vaporization of the mixed fuel takes place in the compression stroke. Thus, absorbing heat from the engine cylinder increases thermal efficiency [27]. Another reason for the increase in efficiency is better combustion due to the existence of oxygen in the propanol percentage of mixed fuel [28].

3.3. Environmental Impact of Propanol-Enriched Gasoline

Propanol-enriched gasolines emit a few gases from the exhaust of the test engine, including CO, CO₂, HC, and NO_x. With propanol-gasoline blended fuels, HC and CO emissions were significantly dropped, whereas the rest of the two gases showed the opposite results.

The improper combustion of the mixed fuel results in the emission of CO gas from the exhaust of the engine, and its variations are shown in Figure 6. The concentration of CO emissions increased for all the fuel mixtures for every speed of the engine. The increase in CO emissions is mainly due to the enhanced fuel consumption with respect to time. At high engine speeds, the engine produced lesser CO emissions than pure gasoline because of the increase of propanol content in the fuel mixture. The CO emissions approximately decreased by 22.1% and 40.1% for P9 and P18, respectively, compared with unmixed gasoline. The highest reductions in CO emissions were observed at 2000 rpm and 1700 rpm with a value of about 37.7% and 54.8% for P9 and P18, compared to P0.

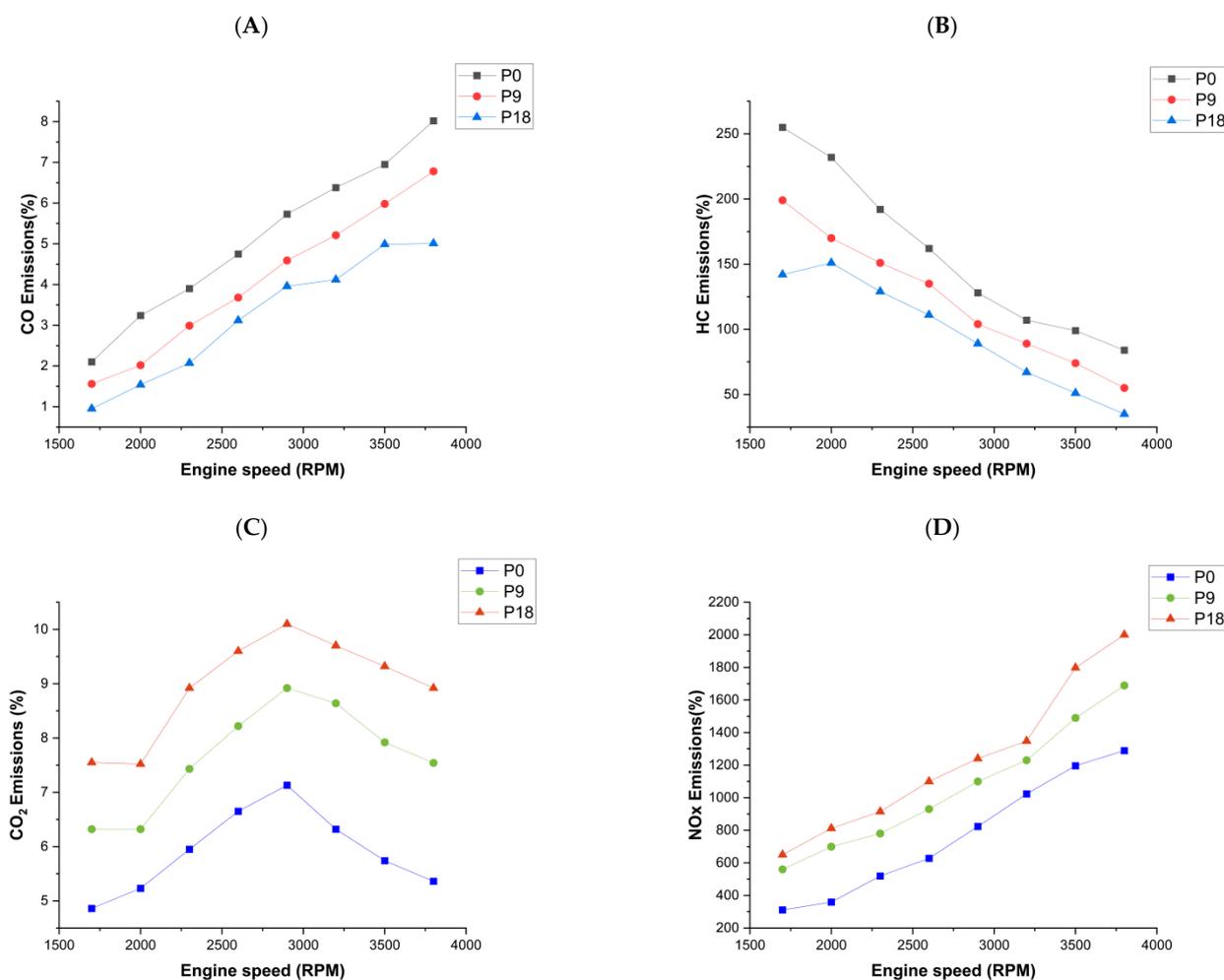


Figure 6. (A–D) Variations in CO, HC, CO₂, and NO_x emissions for the three fuels.

Moreover, propanol contains oxygen content which, when mixed with gasoline, produces a lean mixture, and during combustion, it produces relatively lesser CO emis-

sions [13]. Variations in HC emissions as a function of engine speed (RPM) with regular intervals from 1700 to 3800 rpm is shown in Figure 6. It clearly shows that HC emissions decrease as the engine speeds (RPM) increase. Due to the homogeneous air-fuel mixture at elevated engine speeds, the cylindrical pressure and temperature show high values, thus improving fuel combustion and reducing HC emissions. In comparison with P0, HC emissions decreased by 22.8% and 39.8% for P9 and P18, respectively. Its highest drop in HC emissions was observed at 3800 rpm with a decrease of 34.5% and 58.3% for P9 and P18, respectively, compared to pure gasoline. The main reasons behind these reduced HC emissions are the ratio of oxygen, and high flame propagation of the mixed fuel [29], thus, resulting in complete combustions and thus reducing HC discharge [30].

Adding propanol in the gasoline makes a mixture with a reduced hydrocarbon fraction that results in lesser HC emissions [11]. On the other hand, CO₂ is the major component in greenhouse gases released due to the burning of fuels in the engines. According to the air-fuel stoichiometric ratio, combustion should only have two products, i.e., H₂O and CO₂. However, in actuality, incomplete combustion results in various other unwanted particles and emissions in the air during the intake stroke. Figure 6 shows the variation of the CO₂ concentrations, with respect to the varying engine speeds (RPM), and clearly shows the increase in CO₂ concentrations with the increase in engine speeds. This trend continues until 2900 rpm, where the CO₂ emissions are the highest, and then start decreasing after 2900 rpm. The blended fuels showed 30.0% and 52.2% elevated CO₂ emissions for P9 and P18, respectively, compared to P0. As CO₂ is directly related to almost all the engine parameters such as brake torque, fuel consumption, and thermal efficiency, an increased amount of blended fuel will be required to produce the same brake power at constant throttle.

Moreover, the ratio of oxygen in mixed fuels is mainly responsible for enhanced combustion and increased CO₂ emissions [31]. The air intake in spark-ignition engines also contain nitrogen gas and other gases that flow inside the combustion chamber. The key causes behind the NO_x emissions through the exhausts of SI engines are enhanced temperature, ratio of oxygen, and the time of air residence in the cylinder [32]. Graphical analyses of the NO_x with respect to engine speeds are shown in Figure 6. The graph clearly shows that NO_x emissions increase with the engine speed due to the increase in temperature of the engine. The increase in NO_x emissions was approximately 47.8% and 71.8% for P9 and P18, respectively, compared with P0. The increase in the BTE for the blended fuels is related to the high pressure and temperature of the cylinder, consequently raising NO_x emissions.

The coefficient of variance (COV) was calculated for each measured quantity. It represents the standard deviation of the measured variable quantity expressed as a percentage of its mean value. In light of estimated values, the measurements recorded could be repeated (see Table 3). Using the determined facts, reliable conclusions can be built up for the effects of the test fuels on the performance of SI engines.

Table 3. Co-efficient of variance for measured quantities.

Measured Quantity	P0	P9	P18
CO	0.389	0.455	0.484
CO ₂	0.129	0.122	0.107
HC	0.405	0.408	0.446
NO _x	0.487	0.372	0.382

4. Conclusions

Lubricant oil parameters were analyzed against unused lubricant oil in this study for three different fuel compositions. Additionally, the engine performance characteristics and emission properties of the tested blended fuels were compared. The following conclusions can be drawn based on the findings:

- i. Compared to fresh lubricating oil, the kinematic viscosity of P9 lube oil exhibited the highest drop, i.e., 36.2% at 40 °C. At the same time, the flash point temperature showed the highest drop, i.e., 27.25% for P0. In the P18 lubricating oil, the highest TBN was also reduced by 29.9%. While using P18, higher concentrations of metal particles were found in the lubricating oil, i.e., (Fe (27 PPM), Al (11 PPM), and Cu (14 PPM).
- ii. Compared to fresh lubricating oil, zinc additives were decreased by 18%, 11%, and 7% for P18, P9, and P0, respectively; calcium additives were lowered by 15%, 10%, and 5%, respectively.
- iii. The engine brake power (BP), brake thermal efficiency (BTE), and engine torque enhanced as the fuel blend's propanol ratio was elevated. The most significant values for BP and BTE were found in P18, which were 37.5% and 18.4% higher than pure gasoline (P0), respectively.
- iv. Blended fuels had the lowest HC and CO emissions. In comparison with gasoline, the typical reductions in emissions for P9 and P18 were CO at 22.1% and 40.1%, respectively, and HC at 22.8% and 39.8%, respectively. CO₂ and NO_x emissions were enhanced in the case of propanol–gasoline mixtures. The average increase in CO₂ emissions for both blended fuels were 30.0% and 52.2%, respectively, whereas the increase in NO_x emissions for P9 and P18 were 47.8% and 71.8%, respectively, when compared with gasoline levels.

This research will help researchers and industry employees design lube oils for blended fuels to get the most out of spark-ignition engines. Refined lube oil can be developed for propanol-blended fuel to minimize deterioration of the lubricant oil, while also improving engine performance and emissions.

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