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A Comparison of Performance, Emissions, and Lube Oil Deterioration for Gasoline–Ethanol Fuel

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Abstract: Over the years, due to the surge in energy demand, the use of alternative fuels has emerged as an interesting area of research. In the current work, a comparative study was conducted by employing gasoline, 6% ethanol–gasoline (E6), and 12% ethanol–gasoline (E12) in a spark-ignition engine. Performance, emissions, and lube oil damage tests were conducted at a constant load by varying engine speed. E12 showed improved performance, i.e., 7.82% higher torque and 14.69% improved brake thermal efficiency (BTE) in comparison with neat gasoline. In addition, CO, CO_2, HC, and NO_x emissions were found to be minimal for E12. Furthermore, lubricating oil properties (kinematic viscosity, flash point, and total base number (TBN)) and wear debris (iron, aluminum, and copper) showed a visibly improved performance with gasoline compared to E6 and E12. The highest decline in kinematic viscosity of 27.87%, compared to fresh oil, was recorded for E12. Thus, the lube oil properties have to be modified according to the chemical properties of the alternative fuel.

Keywords: ethanol; performance; emissions; lube oil; additives; metal particles

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1. Introduction

Fossil fuels are the most sought-after sources of energy and have become an integral part of everyday life [1,2]. Their extensive extraction is threatening our future generations' access to energy. The burning of fossil fuels produces various pollutants and is the leading cause of pollution and greenhouse emissions [3,4]. The looming threat of inflated demand, dwindling fuel reservoirs, and environmental damage has sparked an immediate need for viable alternative fuels. In such circumstances, scientists and researchers are vying to mitigate these problems by researching alternative fuels and have identified ethanol–gasoline blends as a viable source with great potential for use in the automotive sector [5,6]. In addition, methanol, hydrogen, propane, electricity, and bio-diesel are all viewed as alternatives to fossil fuels such as gasoline or diesel [7,8]. Even though their use is growing, they are unlikely to totally replace diesel and gasoline very soon. However, it is necessary to make the change gradually.

Ethanol is manufactured from a variety of plant resources called "biomass" and is termed a renewable fuel [9]. It is a colorless, clear liquid and is also referred to as EtOH, grain alcohol, and ethyl alcohol [10,11]. Upwards of 98% of United States gasoline incorporates ethanol, usually 10% ethanol with 90% gasoline. This is performed to oxygenate the fuel, which lessens air pollution. It has a greater octane number than simple gasoline, making it ideal for blending. However, it provides less energy per liter than gasoline, based on the volume proportion of ethanol inside the blend. Being an anti-knock additive or octane enhancer contributes to the efficiency of today's higher compression engines.

There has been immense research carried out regarding the utilization of ethanol in automobile engines. F.A.K. Thakur et al. conducted a comparative study of the performance of different ethanol–gasoline blend ratios in SI engines. They concluded that ethanol blends of lower proportions demonstrated improvement in the brake power and torque. E10 and E20 showed increases of brake power up to 2.77% and 4.16%, while torque increased by 0.59% and 4.77% [12]. Moreover, higher ethanol content resulted in higher BSFC. E30, E75, and E100 demonstrated improvement in torque by 20%, 37%, and 56%. M.K. Mohammed et al. conducted similar research, using ethanol–gasoline blends in an SI engine at different operating speeds. They found a 25.8% increase in thermal efficiency with the E40 mixture compared to commercial gasoline. Similarly, the E40 mixture was found to have the maximum decrease in BSFC and exhaust emissions [13].

Paolo Iodice et al. researched the effects of ethanol–gasoline blends in the warm-up phase of an SI engine. Their research concluded that, with the use of ethanol in oxygen-free gasoline, cold emissions were decreased [14]. Similarly, C.B. Ribeiro et al. evaluated exhaust and performance parameters of non-road SI engines at varying loads through ethanol–gasoline blends of E0, E10, E20, and E27. The study concluded that a higher oxygenated ethanol content in gasoline had a greater positive impact on emissions reduction than compared to the impact on performance and fuel consumption [15,16]. Dongyoung Jin et al. investigated the emissions from various ethanol–gasoline blends used in a spark ignition direct injection (SIDI) engine. They concluded that fuel economy reduced by 29% when using the E85 blend compared to pure gasoline [17]. Ahmad O. Hasana et al. studied the effect of ethanol–gasoline blends on engines of different combustion chamber geometries. Five different compression ratios were chosen for the experiment with a full throttle: 4:1, 5.5:1, 7:1, 8.5:1, and 10:1. The brake specific fuel consumption, brake mean effective pressure, and brake thermal efficiency were found to be higher at all compression ratios than pure gasoline. The ethanol–gasoline blends were found to be less detrimental to the environment through reduced exhaust emissions.

Butanol and methanol are other similar compounds that are blended with gasoline, and there has been a lot of research carried out with them parallel to ethanol. M. Mourad et al. conducted a study blending ethanol and butanol separately with gasoline, testing their performance and emissions in an SI engine. They incorporated different blends ranging from 2% to 20% and reported a clear reduction in pollutants: 25.2% hydrocarbon reduction and 13.7% carbon monoxide reduction. The fuel consumption and engine power decreased by 8.22 and 11.1, respectively [18]. Budi Waluyo et al. conducted a performance test of stable, homogenous, gasoline–ethanol–methanol blends on an SI engine and revealed that the blend produced more power compared to pure gasoline in all working conditions as a result of its laminar combustion speed [19].

If the gasoline is not fully burned off in the combustion chamber, it leaks into the crankcase and mixes with oil. This causes oil dilution, reducing the viscosity of the oil. Much research has been conducted on the effect of blends on engine lubricating oil. In this context, Krishna Chowdary et al. investigated the sustainability of methanol and ethanol diesel blends by analyzing the damage to the engine lubricating oil. The fuel blends used were BE10 (10% ethanol, 90% diesel) and BM10 (10% methanol, 90% diesel). The research revealed that using diesel resulted in 7.2% more density compared to BM10 and BE10. The blending of fuel proved favorable in terms of improved oil performance; however, the appearance of the moisture was unwelcome, which was potentially contained by the addition of suitable additives [20]. Usman et al. conducted the comparative evaluation of CNG and gasoline for lubricating oil deterioration and reported that the zinc and calcium additive depletion rate was significantly lower for CNG compared to pure gasoline [21]. Similarly, another study of lubricating oil deterioration was conducted for gasoline, CNG, and CNG–HHO by Usman et al. The results rendered the CNG–HHO blend unsuitable for lubricating oil, as the wearing of properties and additive depletion rate were higher compared to other fuels [22].

In the light of the literature cited, it is evident that much work has been reported regarding evaluating the performance and emissions of gasoline blended with ethanol in varying concentrations. However, there have been scarce efforts carried out so far for considering the damage imparted to the lubricating oil for the same fuel. In the current work, ethanol is blended with gasoline in concentrations of 6 and 12% by volume, and performance, emissions, and lubricating oil deterioration have been comparatively evaluated. The engine was operated for 80 h straight, and lube oil samples were collected and tested according to the standards. Thus, in addition to the performance and emissions aspect of ethanol blending, a novel lube oil deterioration measurement method has been introduced, which could be used for feasibility assessment of alternative fuel.

2. Methodology

In the current work, a single-cylinder, 4-stroke, naturally aspirated, air-cooled spark ignition engine was used. The specifications of the engine are listed in Table 1. The testing was conducted by coupling the engine with the DYNOMAX water brake dynamometer by means of pipes, load control valves, and pumps. The schematic of the experimental setup is shown in Figure 1. First, the engine was tested at a maximum load of 30 psi in the speed range of 1300–3700 rpm. The load of 30 psi was selected for considering the maximum effect on engine performance characteristics. The performance was recorded through a data acquisition system and was processed for obtaining the engine performance parameters. For the emission analysis, the EMS-5002 emission analyzer was incorporated. For each observation, the probe of the analyzer was inserted into the exhaust manifold and was kept there until the fluctuations started diminishing. Next, the experiment was repeated at the same test conditions but with ethanol blending into gasoline in 6% and 12% by volume concentrations. In addition to performance and emissions, the effect of fuels on lubricating oil deterioration was also evaluated. The fresh engine oil was tested according to ASTMD standards, and properties were recorded. Finally, after the constant engine operation with three fuels for 80 h, their deterioration in properties, the introduction of foreign metallic particles, and wearing of additive depletion were comparatively evaluated.

Table 1. Engine specifications.

Feature	Specification
Engine Model	HONDA GP 160
Engine Type	Overhead Valves Petrol Engine
Bore (mm)	68
Stroke	45
Cylinder Orientation	25° incline cylinder
Displacement (cc)	163
Net Power (kW)	3.6
Maximum Torque (Nm)	10.3 at 2500 rpm
Rated Power (kW)	2.5 at 3000 rpm
Ignition System	Transistorized

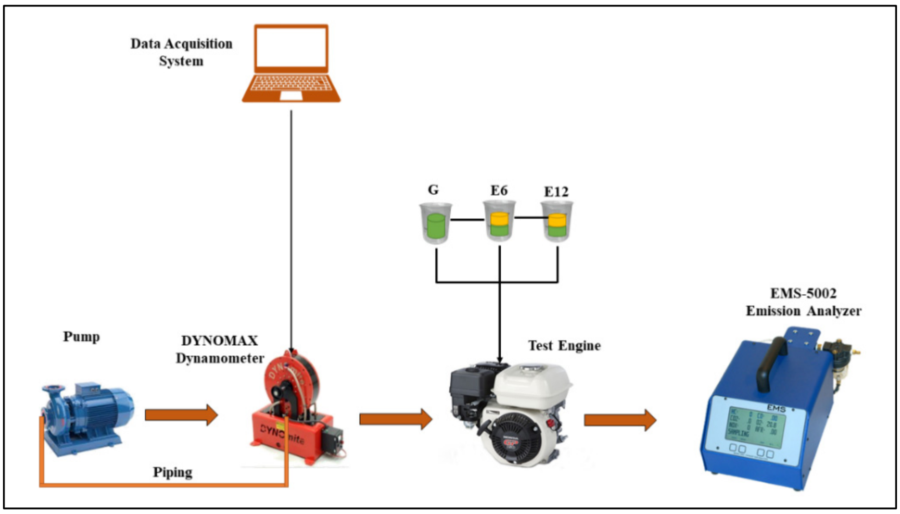

Figure 1. Schematic of experimental setup.

3. Results and Discussion

3.1. SI Engine Performance and Brake Thermal Efficiency

Variations in brake torque with engine speed for the test fuels over the entire speed range are shown in Figure 2. All the fuels are showing an increasing trend up to an optimum speed of 2800 rpm and are later seen declining. On a comparative scale, twelve percent by volume ethanol in gasoline (E12) generated 7.82% higher torque than pure gasoline. Moreover, E6 generated an average of 3.58% lesser torque than E12. The improved torque with the ethanol addition to gasoline could be attributed to the three times higher latent heat of vaporization of ethanol than gasoline, which results in higher volumetric efficiency and higher effective mean pressure which consequently generate high torque [23].

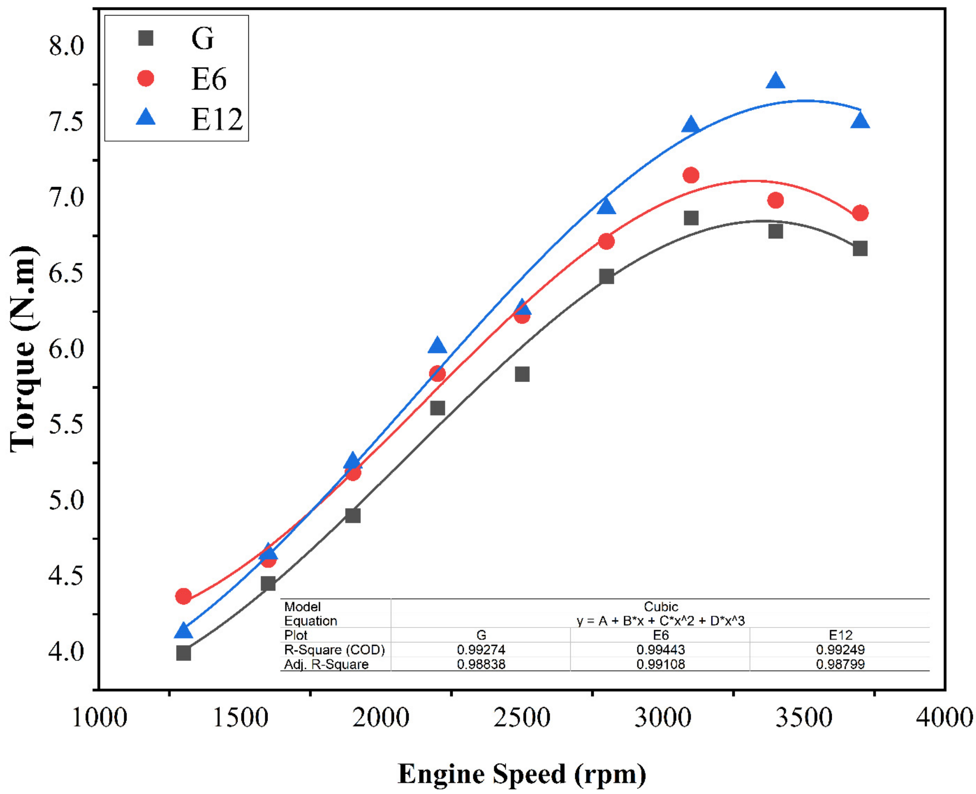

Figure 2. Torque variation with engine speed.

The comparative behaviors of gasoline, E6, and E12 fuels in terms of brake power are depicted in Figure 3. The comparison established E12 as the best performing fuel. The average percentage increase for E6 and E12 at each engine speed was found to be 4.11% and 10.39%, respectively. All test fuels were directly correlated with speed, as higher power is produced with augment revolutions of the engine crankshaft. The improved power production at the output shaft is due to the addition of ethanol to gasoline. The alcoholic blend promotes the lean burning through improving the air/fuel equivalence ratio. This results in improved combustion and consequently higher power production [24,25].

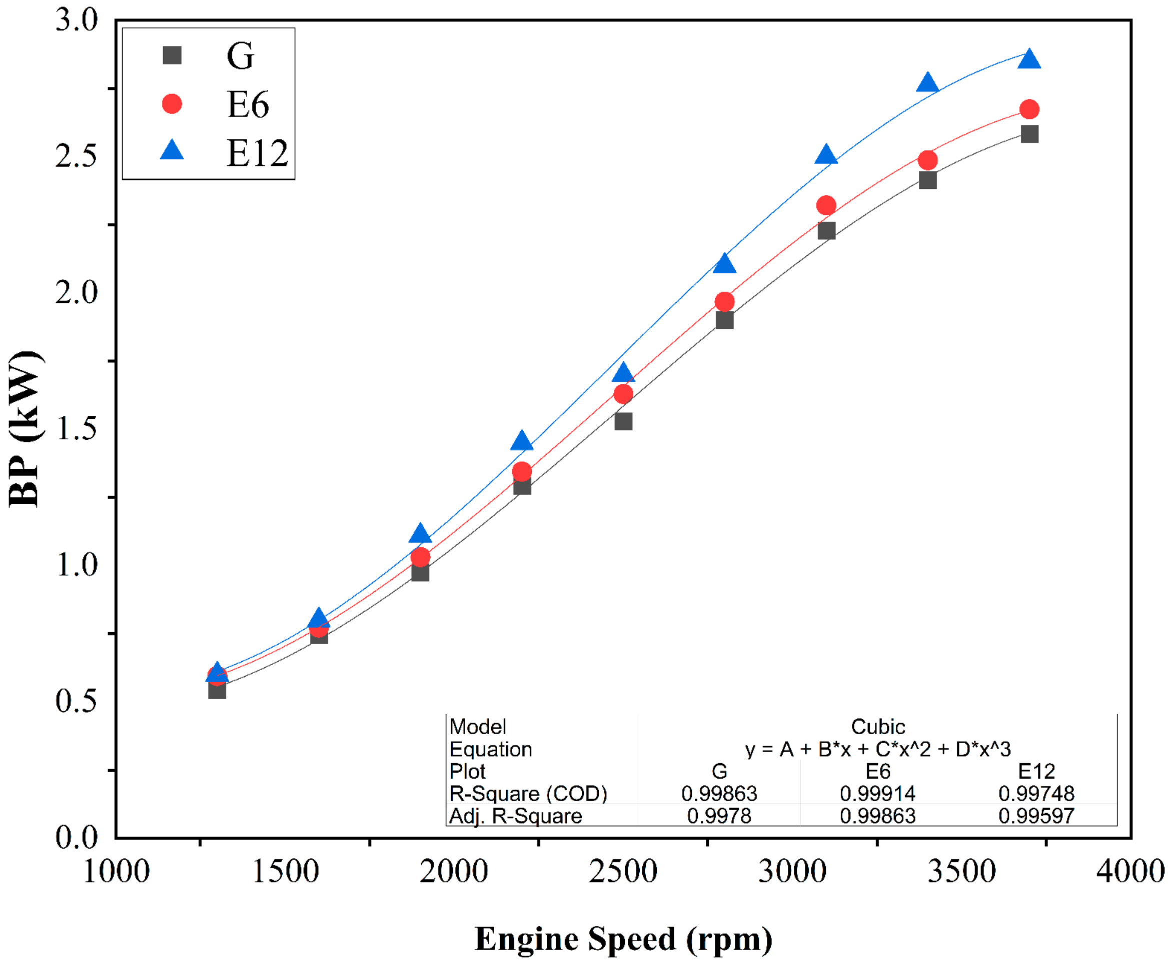

Figure 3. Brake power variation with engine speed.

The variation patterns of BSFC with engine speed for different ethanol concentrations are shown in Figure 4. It was observed that increasing the ethanol concentration increased the BSFC values. The maximum BSFC was observed for E12 at every engine speed, followed by E6. The maximum BSFCs for gasoline, E6, and E12 were observed at a lower engine speed of 1300 rpm. The maximum percentage increase in BSFC for E6 and E12 were 31.34% and 33.008% at 3400 rpm. The average percentage increase compared to gasoline for E6 and E12 was 8.60% and 11.57% at every rpm value. The increasing trend for the BSFC with an increase in ethanol percentage could be attributed to the heating value. Gasoline has a higher heating value than ethanol at the same operating conditions [26]. Although increasing the ethanol concentration increases the overall octane value of the fuel, at the same time it decreases its lower heating value (LHV). Eventually, more blended fuel would be burnt to accomplish the exact energy requirements under the same operating conditions, as evident from the trends [24].

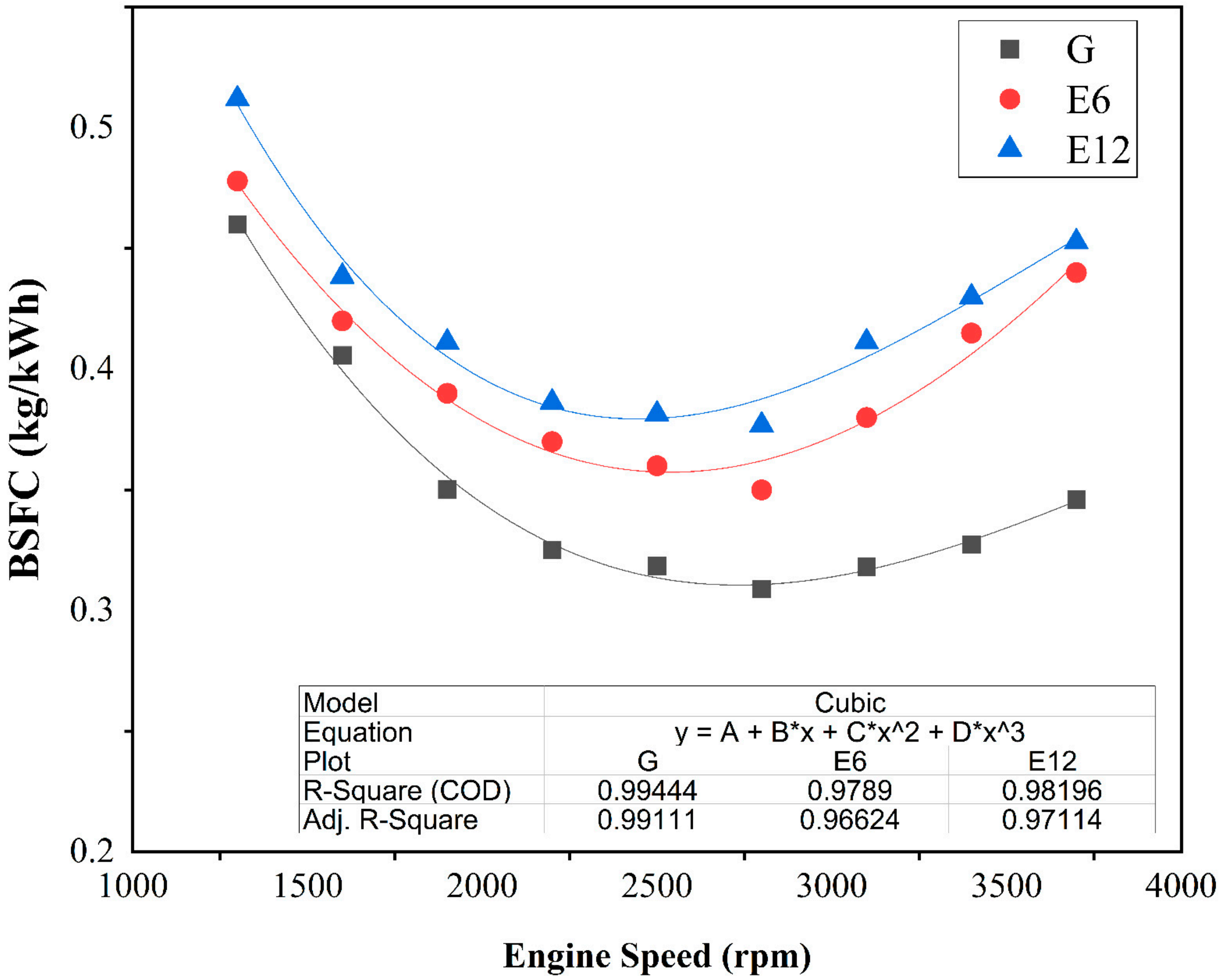

Figure 4. BSFC variation with engine speed.

The effects of engine speed and ethanol concentrations on BTE are comprehensively shown in Figure 5. The peak values of BTE for G, E6, and E12 were in the speed range of 2200–2800 rpm. The ethanol blend with gasoline emerged favorable owing to higher thermal efficiencies over the entire speed range compared to pure gasoline both for E6 and E12. The maximum BTE of 24.43% was observed for E12 at a speed of 2800 rpm.

3.2. Engine Emissions Assessment

Figure 6 depicts the variation in concentration of CO emissions with engine speed for gasoline, E6, and E12 at a constant load of 30 psi. E12 emerged beneficial owing to the 22.35% lower CO emissions in comparison with neat gasoline. Moreover, the emissions for E6 were in between pure gasoline and E12. CO emission is generically associated with incomplete combustion inside the engine cylinder. The reduced emissions with the ethanol addition to gasoline could be attributed to the oxygen content of ethanol, which facilitates complete combustion [28]. Moreover, the presence of ethanol in gasoline augments the amount of intake air, which will lead to the lean combustion process [29]. In addition, the increment in engine speed consequently showed higher CO emissions for all the test fuels. The concentration of CO emissions at 3100 rpm was 6.74 ppm, 5.09 ppm, and 4.64 ppm for E0, E6, and E12 and changed to 7.32 ppm, 5.84 ppm, and 5.38 ppm for the respective fuels at a speed of 3400 rpm. This decline could be ascertained by the lesser time available for the combustion process at high engine speeds [30].

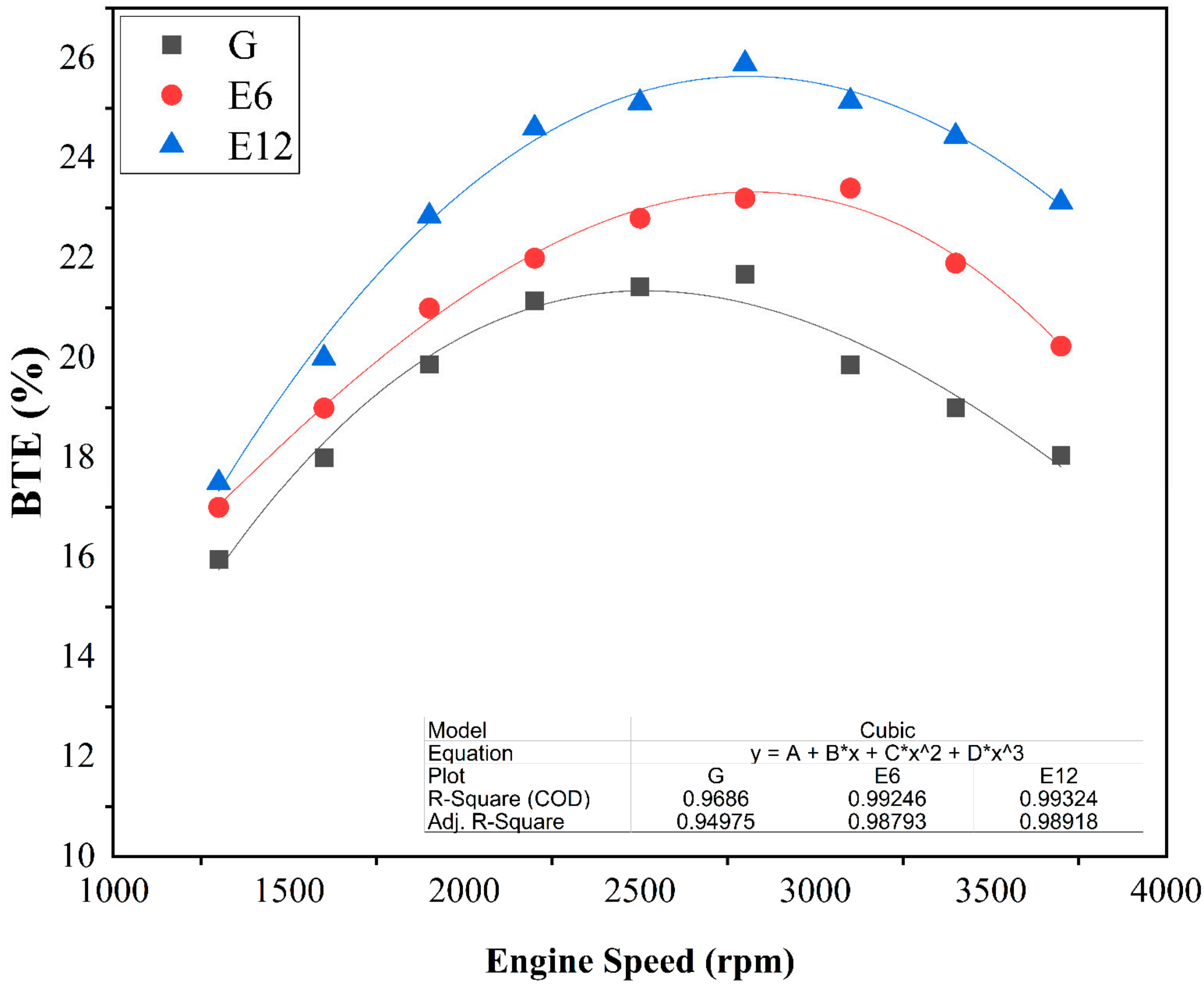

Figure 5. BTE variation with engine speed.

Compared to G, the increased percentages in the BTE for E6 and E12 were 6.03% and 14.69%, respectively, at a speed of 2500 rpm. Moreover, E6 and E12 showed an average increment of 8.149% and 16.12% in comparison to neat gasoline. This increase in BTE with ethanol could be attributed to the supplemented oxygen provided by the alcoholic fuel [27]. Thus, ethanol increased the oxygen content, which decreased the required air/fuel ratio (AFR), facilitating the efficient combustion in the combustion chamber [25].

The variations in concentration of CO_2 relative to change in engine speed at a constant load of 30 psi for three different fuels are shown in Figure 7. In the context of greenhouse gas emission, ethanol blending proved undesirable, as E6 and E12 showed averages of 13.39% and 33.60% higher emissions than neat gasoline. The tested fuels showed the peak emissions at an engine operating speed of 2800 rpm in the increasing–decreasing curve pattern. Beyond a particular speed, the emission decline for pure and blended fuels as time required for complete combustion is drastically reduced. This is because of the high oxygen content of partially oxidized hydrocarbons [31]. The ethanol–gasoline blends are recognized as partially oxidized hydrocarbons. Therefore, the high oxygen content supports the process of combustion and declines the incomplete combustion in fuel-rich areas. As a result, carbon monoxide and hydrocarbon emissions are reduced, and carbon dioxide emissions are increased [32].

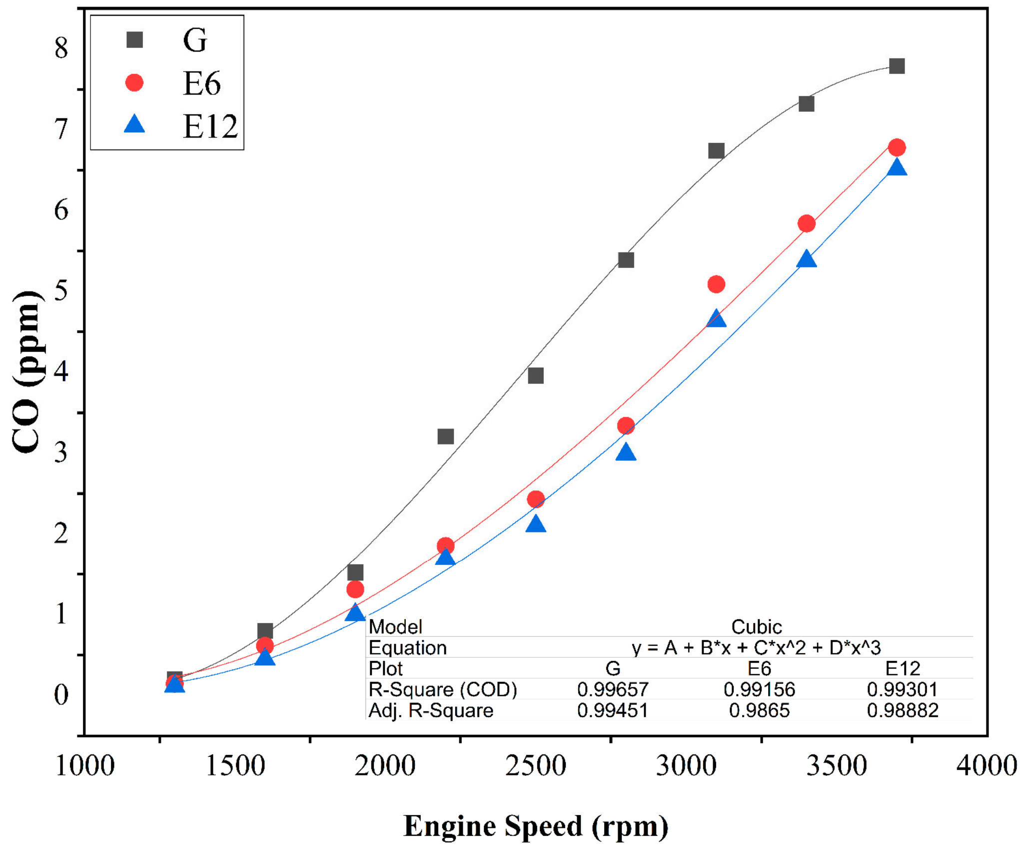

Figure 6. CO variations with engine speed.

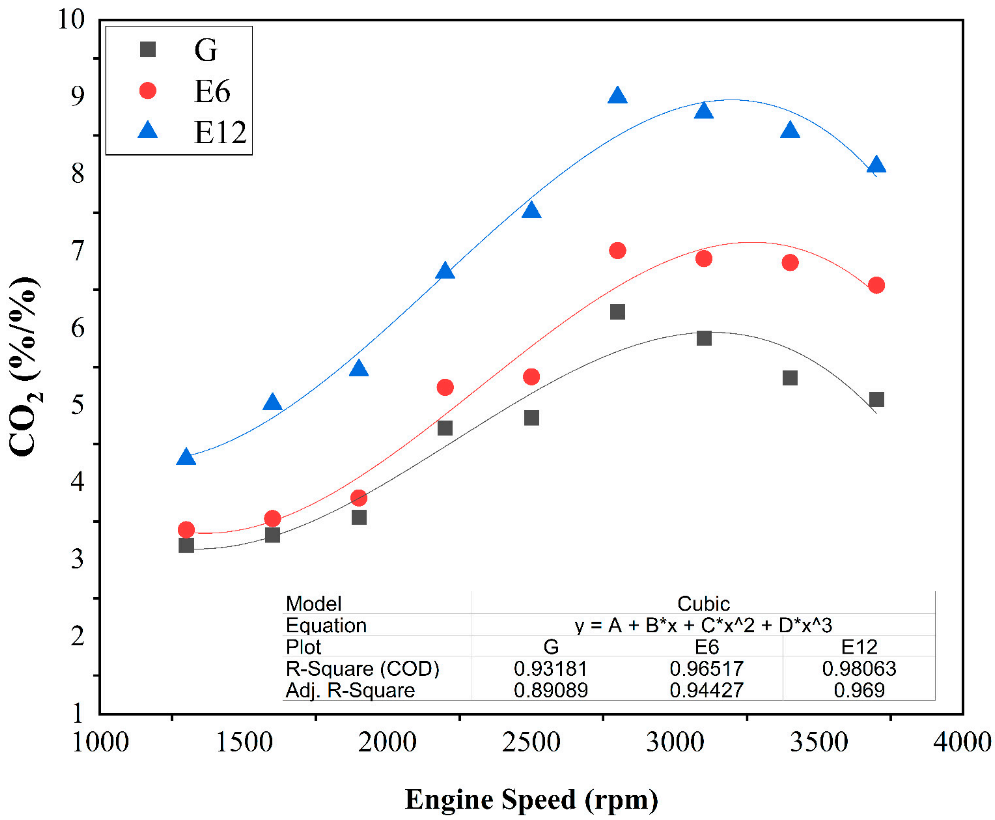

Figure 7. CO_2 variation with engine speed.

The variations in the concentration of the HC emissions relative to engine speed for the three fuels are shown in Figure 8. The HC emissions were found to be maximum for gasoline and minimum for E12. For the whole experimental range, E12 produced 32.20% and 23.29% lower hydrocarbons than neat gasoline and E6. Moreover, for all three fuels, the maximum HC were observed for the lowest engine speed of 1300 rpm. The formation of hydrocarbons is inherently due to the unburnt portion of fuel, which is released into the environment in the form of exhaust gases. Thus, the reduced emissions with ethanol blending could be apprehended by the improved combustion process due to the oxygen content of alcoholic fuels [33]. The emission patterns of nitrogen oxides over the entire speed range for gasoline, E6, and E12 are shown in Figure 9. Unlike to other emissions, ethanol blending with gasoline resulted in higher NO_x formation compared to pure gasoline. The unblended fuel emerged least damaging to environment with 63.3% and 74.9% lower emissions compared to E6 and E12, respectively. The curves are seen following an increasing pattern with the increment along the abscissa for all fuels. The formation of nitrogen oxides within the engine cylinder is highly temperature dependent [34,35]. The increase in engine speed is supported by more fuel combustion; therefore, NO_x formation is also higher. Moreover, the increment with the ethanol addition is due to the higher cylinder temperature in the link with complete combustion facilitated with the oxygen presence.

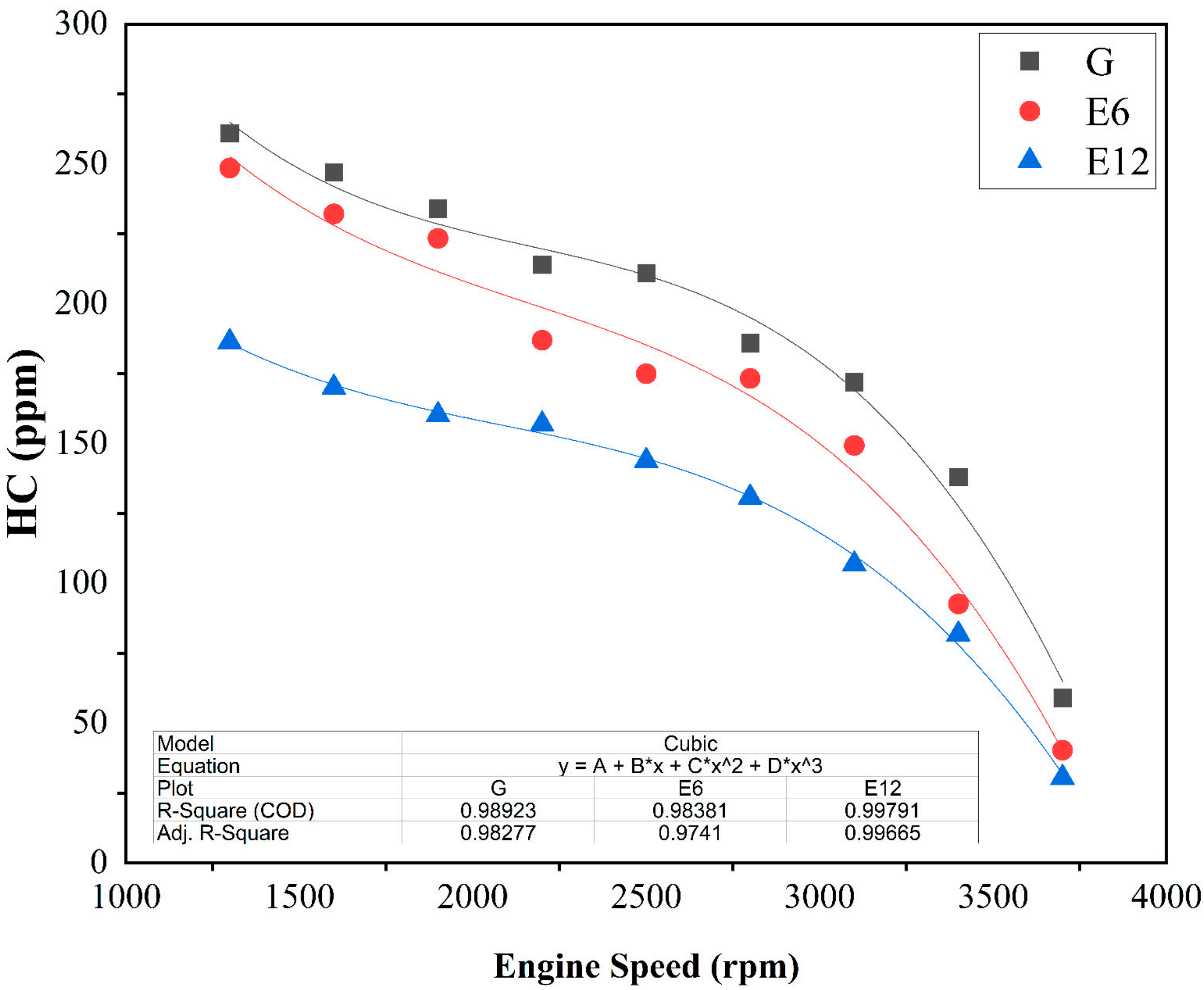

Figure 8. HC variation with engine speed.

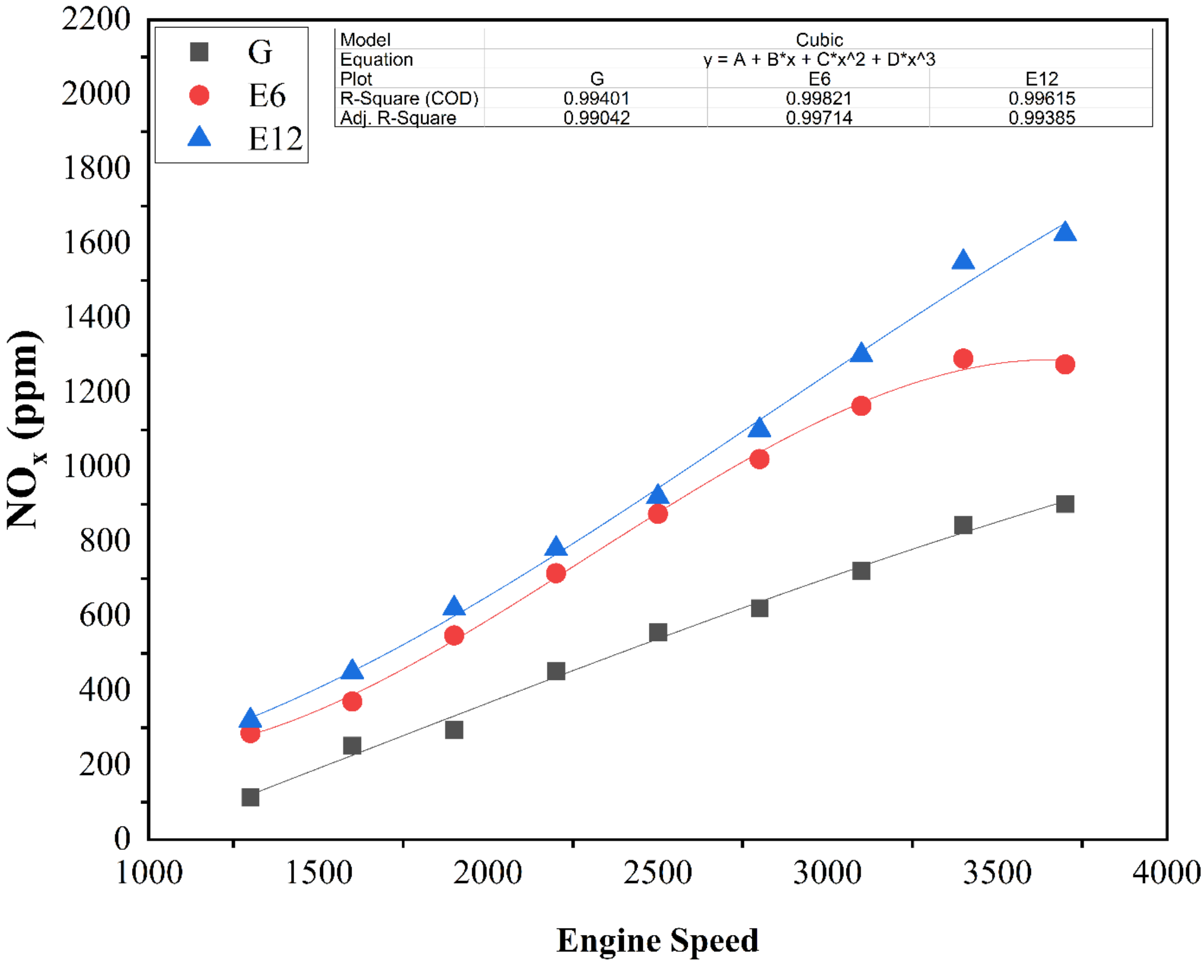

Figure 9. NO_X variations with engine speed.

3.3. Lubricating Oil Deterioration

Engine lubricating oil is essential for smooth operation. Its primary functions are to prevent the direct contact of rotating parts as well as to reduce friction. It is essentially composed of basic oil as well as distinct additives, with each performing the desired purpose. In this section, the effect of ethanol addition on the engine oil deterioration has been considered after 80 h of engine operation. First, the variations in chemical properties were comparatively evaluated for gasoline, E6, and E12. Later, the additive depletion was comprehensively studied for thorough investigation of the feasibility of incorporating ethanol as an alternative fuel.

3.3.1. Chemical and Physical Properties

After the engine operates for a specific duration, the lubricating oil begins to deteriorate and needs an immediate replacement for promising efficiency and emissions. The chemical properties considered in this section are kinematic viscosities at temperatures of 40 and 100 degrees Celsius, flash point, and total base number (TBN), as shown in Figure 10. The comparative evaluation was made based on the fresh oil properties. Kinematic viscosity refers to the time the oil will need to flow from one point to the other. Engine oil with higher kinematic viscosities is desirable for efficient operation, friction control, fuel efficiency, and emissions. Viscosities, when compared, evaluated at a lower temperature, and gasoline showed the most promising results followed by the E12 and E6. For gasoline, E6, and E12, the viscosity decreased by 15.31%, 29.93%, and 27.87%, respectively. Similarly, for higher temperature viscosities, the values are lower but are seen following the same decline pattern. The rapid decline in viscosity with oxygenated fuels would negatively impact engine performance, as there would be more resistance against the moving parts, which is generally associated with the breakdown of molecules and corrosion [36].

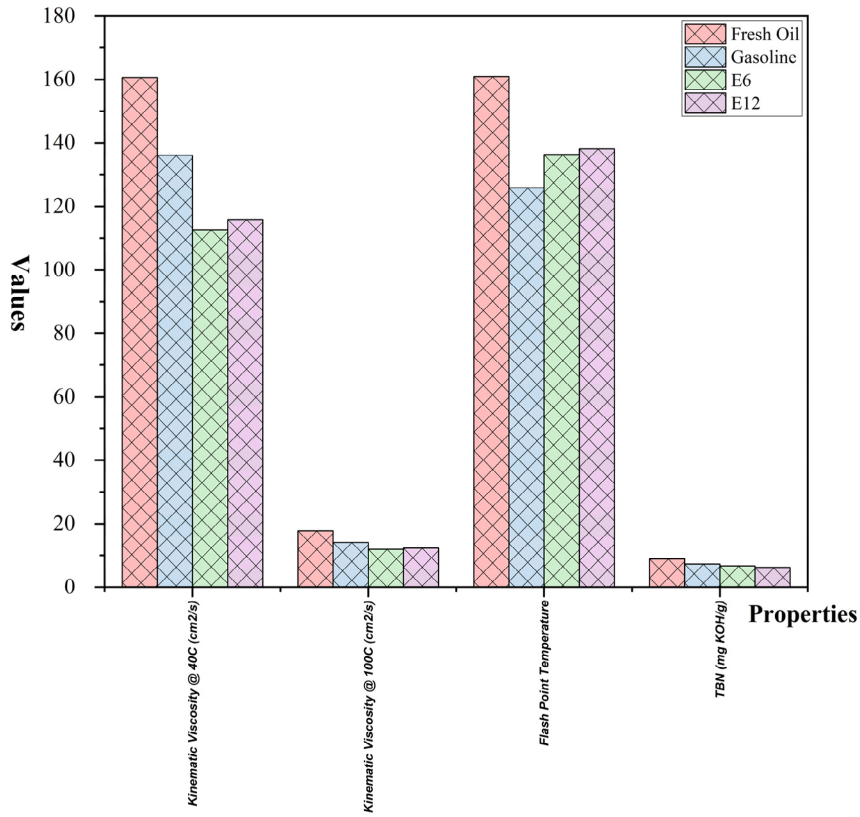

Figure 10. Comparison of lube oil properties.

Considered from the declining viscosity aspect, it establishes that, for preventing the lube oil deterioration, the alcoholic fuel should be avoided. The second property evaluated was the flash point, which is the minimum temperature at which the vapors of the fuel will ignite once provided with the spark. The flash point should ideally be high for efficient engine operation. Compared to fresh oil, gasoline showed the most significant decline of 21.8% for flash point, then E6 (15.3%) and E12 (14.22%). This discussion put forward that, for preventing rapid lube oil deterioration for the same engine operation duration, alcoholic fuel is preferable. Moreover, the total base number (TBN), which measures the alkali nature of oil, has also been comparatively evaluated for all three test fuels. The decline of the TBN was a very minute amount compared to fresh oil; however, the gasoline fuel emerged better in terms of having less decline. Moreover, the decrease in the TBN was comparable for both ethanol-blended fuels.

3.3.2. Suspended Particles

The oxidation products are lethal for engine oil. This process is excessive and may become uncontrolled when foreign particles are introduced; therefore, it must be potentially considered [37]. Lubricating oil deterioration in terms of iron (Fe), copper (Cu), and aluminum (Al) occurrence for neat and blended fuels is shown in Figure 11.

The visualization reveals that, with the addition of ethanol to gasoline, the contamination rates were significantly higher compared to gasoline. Iron was found to be the highest in concentration for all fuels, followed by copper and aluminum. Thus, regarding deterioration in terms of Fe and Al suspended particles, E12 emerged 31.1% and 50% more lethal than gasoline.

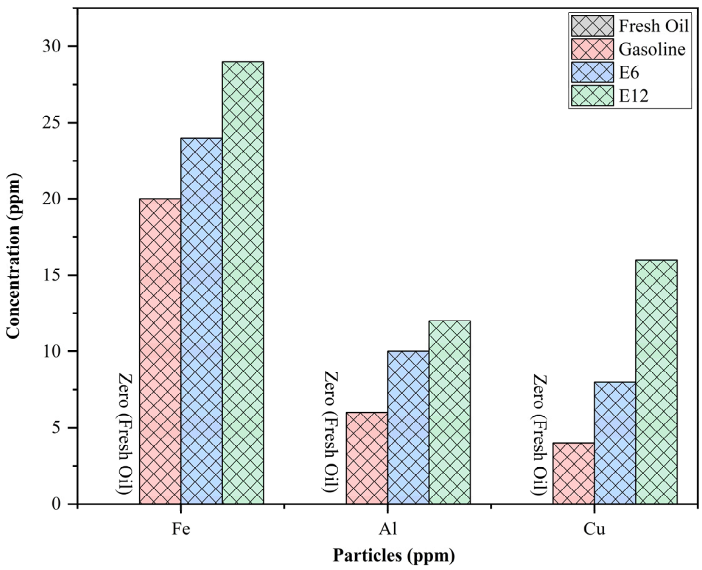

Figure 11. Comparison additive depletion rate.

4. Conclusions

This research presents the performance, emissions, and lubricating oil deterioration of SI engines operating with ethanol–gasoline blends at a constant engine load. The comparative evaluation of performance parameters revealed that E12 showed an average 5.27% higher torque than gasoline. Moreover, the ethanol blending showed an average of 18.64% and 19.96% improved brake thermal efficiency for E6 and E12 in comparison to pure gasoline. Similarly, CO and HC emissions decreased for E6 and E12, with the latter experiencing greater variations. In a trend dissimilar to other emissions, CO_2 and NO_x increased with ethanol blending. The lube oil deterioration comparison revealed that kinematic viscosities of lubricating oils with gasoline, E6, and E12 decreased by 15.31%, 29.93%, and 27.87% compared to fresh oil at 40 °C. The depletion rate of iron for E12 was 50% higher than for pure gasoline.

Thus, the addition of alcohol to gasoline emerged favorable in terms of improved performance and reduced emissions, to some extent. However, the undesirable impact on engine lubricating oil in terms of properties variations and contamination is an important aspect of the research.

5. Future Work

The authors aim at the preparation of a lubricating oil that best suits alcoholic fuels. Moreover, the lube oil deterioration will also be tested at higher concentrations of ethanol and at varying combinations of speed and load.

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References

1. Mutezo, G.; Mulopo, J. A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. *Renew. Sustain. Energy Rev.* **2020**, *137*, 110609. [CrossRef]
2. Usman, M.; Nomanbhay, S.; Ong, M.; Saleem, M.; Irshad, M.; Hassan, Z.; Riaz, F.; Shah, M.; Qyyum, M.; Lee, M.; et al. Response Surface Methodology Routed Optimization of Performance of Hydroxy Gas Enriched Diesel Fuel in Compression Ignition Engines. *Processes* **2021**, *9*, 1355. [CrossRef]

3. Hanif, I.; Raza, S.M.F.; Gago-De-Santos, P.; Abbas, Q. Fossil fuels, foreign direct investment, and economic growth have triggered CO_2 emissions in emerging Asian economies: Some empirical evidence. *Energy* **2019**, *171*, 493–501. [CrossRef]
4. Usman, M.; Hussain, H.; Riaz, F.; Irshad, M.; Bashir, R.; Shah, M.H.; Zafar, A.A.; Bashir, U.; Kalam, M.A.; Mujtaba, M.A.; et al. Artificial Neural Network Led Optimization of Oxyhydrogen Hybridized Diesel Operated Engine. *Sustainability* **2021**, *13*, 9373. [CrossRef]
5. Iodice, P.; Cardone, M. Ethanol/Gasoline Blends as Alternative Fuel in Last Generation Spark-Ignition Engines: A Review on CO and HC Engine Out Emissions. *Energies* **2021**, *14*, 4034. [CrossRef]
6. Mujtaba, M.; Kalam, M.; Masjuki, H.; Gul, M.; Soudagar, M.E.M.; Ong, H.C.; Ahmed, W.; Atabani, A.; Razzaq, L.; Yusoff, M. Comparative study of nanoparticles and alcoholic fuel additives-biodiesel-diesel blend for performance and emission improvements. *Fuel* **2020**, *279*, 118434. [CrossRef]
7. Bicer, Y.; Dincer, I. Life cycle environmental impact assessments and comparisons of alternative fuels for clean vehicles. *Resour. Conserv. Recycl.* **2018**, *132*, 141–157. [CrossRef]
8. Stančin, H.; Mikulčić, H.; Wang, X.; Duić, N. A review on alternative fuels in future energy system. *Renew. Sustain. Energy Rev.* **2020**, *128*, 109927. [CrossRef]
9. Cardona, C.A.; Sánchez, Ó.J. Fuel ethanol production: Process design trends and integration opportunities. *Bioresour. Technol.* **2007**, *98*, 2415–2457. [CrossRef]
10. Bailey, B.K. Performance of Ethanol as a Transportation Fuel. In *Handbook on Bioethanol*; Routledge: London, UK, 2018; pp. 37–60.
11. Khan, H.; Soudagar, M.E.M.; Kumar, R.H.; Safaei, M.R.; Farooq, M.; Khidmatgar, A.; Banapurmath, N.R.; Farade, R.A.; Abbas, M.M.; Afzal, A. Effect of nano-graphene oxide and n-butanol fuel additives blended with diesel—Nigella sativa biodiesel fuel emulsion on diesel engine characteristics. *Symmetry* **2020**, *12*, 961. [CrossRef]
12. Thakur, A.K.; Kaviti, A.K.; Mehra, R.; Mer, K. Progress in performance analysis of ethanol-gasoline blends on SI engine. *Renew. Sustain. Energy Rev.* **2017**, *69*, 324–340. [CrossRef]
13. Mohammed, M.K.; Balla, H.H.; Al-Dulaimi, Z.M.H.; Kareem, Z.S.; Al-Zuhairy, M.S. Effect of ethanol-gasoline blends on SI engine performance and emissions. *Case Stud. Therm. Eng.* **2021**, *25*, 100891. [CrossRef]
14. Iodice, P.; Langella, G.; Amoresano, A. Ethanol in gasoline fuel blends: Effect on fuel consumption and engine out emissions of SI engines in cold operating conditions. *Appl. Therm. Eng.* **2018**, *130*, 1081–1089. [CrossRef]
15. Ribeiro, C.B.; Martins, K.G.; Gueri, M.V.D.; Pavanello, G.P.; Schirmer, W.N. Effect of anhydrous ethanol/gasoline blends on performance and exhaust emissions of spark-ignited non-road engines. *Environ. Sci. Pollut. Res.* **2018**, *25*, 24192–24200. [CrossRef] [PubMed]
16. Mujtaba, M.A.; Muk Cho, H.; Masjuki, H.H.; Kalam, M.A.; Farooq, M.; Soudagar, M.E.M.; Gul, M.; Afzal, A.; Ahmed, W.; Raza, A.; et al. Effect of primary and secondary alcohols as oxygenated additives on the performance and emission characteristics of diesel engine. *Energy Rep.* **2021**, *7*, 1116–1124. [CrossRef]
17. Cho, J.; Si, W.; Jang, W.; Jin, D.; Myung, C.-L.; Park, S. Impact of intermediate ethanol blends on particulate matter emission from a spark ignition direct injection (SIDI) engine. *Appl. Energy* **2015**, *160*, 592–602. [CrossRef]
18. Ishak, N.M.; Sivakumar, D.; Mansor, M.R. Thermoplastic matrix selection for fibre metal laminate using fuzzy VIKOR and entropy measure for objective weighting. *J. Eng. Sci. Technol.* **2017**, *12*, 2792–2804.
19. Waluyo, B.; Setiyo, M.; Wardana, I.N.G. Fuel performance for stable homogeneous gasoline-methanol-ethanol blends. *Fuel* **2021**, *294*, 120565. [CrossRef]
20. Chowdary, K.; Tated, M.K.; Kotia, A. Effect of Methanol and Ethanol on lubrication oil degradation of CI engine. *J. Gujarat Res. Soc.* **2019**, *21*, 156–166.
21. Usman, M.; Hayat, N. Use of CNG and Hi-octane gasoline in SI engine: A comparative study of performance, emission, and lubrication oil deterioration. *Energy Sources Part A Recovery Util. Environ. Eff.* **2019**, 1–15. [CrossRef]
22. Usman, M.; Hayat, N.; Bhutta, M.M.A. SI Engine Fueled with Gasoline, CNG and CNG-HHO Blend: Comparative Evaluation of Performance, Emission and Lubrication Oil Deterioration. *J. Therm. Sci.* **2020**, *30*, 1199–1211. [CrossRef]
23. Deng, X.; Chen, Z.; Wang, X.; Zhen, H.; Xie, R. Exhaust noise, performance and emission characteristics of spark ignition engine fuelled with pure gasoline and hydrous ethanol gasoline blends. *Case Stud. Therm. Eng.* **2018**, *12*, 55–63. [CrossRef]
24. Mohamad, B.; Szepesi, G.L.; Bollo, B. *Review Article: Effect of Ethanol-Gasoline Fuel Blends on the Exhaust Emissions and Characteristics of SI Engines*; Springer International Publishing: New York, NY, USA, 2018; pp. 29–41.
25. Mourad, M.; Mahmoud, K.J.R.E. Investigation into SI engine performance characteristics and emissions fuelled with ethanol/butanol-gasoline blends. *Renew. Energy* **2019**, *143*, 762–771. [CrossRef]
26. Geng, P.; Furey, R.; Konzack, A. Calculation of Heating Value for Gasoline Containing Ethanol. *SAE Int. J. Fuels Lubr.* **2010**, *3*, 229–237. [CrossRef]
27. Ahmed, M.; Ismail, Y.; Mohamed, M. The influence of ethanol–gasoline blends on performance characteristics of engine generator set. *Am. J. Eng. Res.* **2017**, *6*, 71–77.
28. Saikrishnan, V.; Karthikeyan, A.; Jayaprabakar, J. Analysis of ethanol blends on spark ignition engines. *Int. J. Ambient Energy* **2017**, *39*, 103–107. [CrossRef]
29. Ağbulut, Ü.; Sarıdemir, S.; Durucan, G. The Impacts of Ethanol—Gasoline Blended Fuels on the Pollutant Emissions and Performance of a Spark—Ignition Engine: An Empirical Study. *Int. J. Anal. Exp. Finite Element Anal. (IJAEFEA)* **2018**, *5*, 50–59. [CrossRef]

30. Koç, M.; Sekmen, Y.; Topgül, T.; Yücesu, H.S. The effects of ethanol–unleaded gasoline blends on engine performance and exhaust emissions in a spark-ignition engine. *Renew. Energy* **2009**, *34*, 2101–2106. [CrossRef]
31. Godwin, D.J.; Geo, V.E.; Thiyagarajan, S.; Martin, M.L.J.; Maiyalagan, T.; Saravanan, C.; Aloui, F. Effect of hydroxyl (OH) group position in alcohol on performance, emission and combustion characteristics of SI engine. *Energy Convers. Manag.* **2019**, *189*, 195–201. [CrossRef]
32. Elfasakhany, A. Performance and emissions of spark-ignition engine using ethanol–methanol–gasoline, n-butanol–iso-butanol–gasoline and iso-butanol–ethanol–gasoline blends: A comparative study. *Eng. Sci. Technol. Int. J.* **2016**, *19*, 2053–2059. [CrossRef]
33. Sakthivel, P.; Subramanian, K.; Mathai, R. Comparative studies on combustion, performance and emission characteristics of a two-wheeler with gasoline and 30% ethanol-gasoline blend using chassis dynamometer. *Appl. Therm. Eng.* **2018**, *146*, 726–737. [CrossRef]
34. Usman, M.; Jamil, M.; Riaz, F.; Hussain, H.; Hussain, G.; Shah, M.; Qyyum, M.; Salman, C.; Lee, M. Refining and Reuse of Waste Lube Oil in SI Engines: A Novel Approach for a Sustainable Environment. *Energies* **2021**, *14*, 2937. [CrossRef]
35. Heywood, J.B.; Higgins, J.M.; Watts, P.A.; Tabaczynski, R.J. *Development and Use of a Cycle Simulation to Predict SI Engine Efficiency and NO_x Emissions*; SAE Technical Paper; SAE: Warrendale, PA, USA, 1979; ISBN 0148–7191.
36. Guan, L.; Feng, X.; Xiong, G. Engine lubricating oil classification by SAE grade and source based on dielectric spectroscopy data. *Anal. Chim. Acta* **2008**, *628*, 117–120. [CrossRef]
37. Usman, M.; Saleem, M.W.; Saqib, S.; Umer, J.; Naveed, A.; Hassan, Z.U. SI engine performance, lubricant oil deterioration, and emission: A comparison of liquid and gaseous fuel. *Adv. Mech. Eng.* **2020**, *12*. [CrossRef]