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Article

Isopropanol as a Renewable Additive in Gasoline Blends: Enhancing Octane Ratings for Sustainable Fuel Solutions

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Abstract: This study explored the effect of isopropanol on Research Octane Number (RON) and Motor Octane Number (MON) of different gasoline constituents, such as reformate, isomerate, light straight-run naphtha (LSRN), and heavy straight-run naphtha (HSRN). Considering its high intrinsic octane values, isopropanol was mixed with different volumetric concentrations of each gasoline to assess its potential as an octane booster. Using normal ASTM procedures, the RON and MON of each blend were assessed. The findings showed that the octane levels of all base fuels had significantly increased. LSRN and HSRN showed the biggest gains, while isomerate and reformate showed very modest improvements. It was discovered that adding isopropanol enhanced the mixes' anti-knock capabilities, making them more appropriate for contemporary high-compression engines. The study also emphasizes how crucial it is to optimize blending ratios to balance the increase in octane with other gasoline characteristics like stability and volatility. The experimental results reported that fuel blends' antidetonation performance, as determined by their octane number, varies in the following order: isopropanol > reformate > isomerate > light straight run naphtha > heavy straight run naphtha by octane number. Finally, isopropanol may be a useful and sustainable additive for raising the octane level of gasoline, improving fuel economy and lessening engine knocking.

Keywords: isopropanol; gasoline biofuels; renewable additives; internal combustion engine; alternative fuels; sustainability

1. Introduction

The industrial civilization of today is based on non-renewable energy sources, especially in the transportation sector. Despite advancements in innovative energy vehicles, internal combustion engines remain the dominant power source for cars [1]. The consumption of non-renewable fossil fuels is accelerated by the increase in automobile ownership. In the meantime, the greenhouse effect and acid rain are made worse by the pollutants that come from burning fossil fuels [2,3]. Therefore, producing clean and renewable energy for engines as substitutes for fossil fuels is a robust approach for addressing global energy and environmental challenges [4].

Widely used sustainable fuels incorporate bio-gasoline, hydrogen, alcohols, biogas, and biodiesel [5–8]. Due to their greater energy density per unit volume, alcohols are a superior surrogate fuel for spark ignition engines than hydrogen and biogas [9]. Additionally, vehicles must carry additional high-pressure equipment when using gaseous fuels [10]. Moreover, oxygenates like alcohols, which are extensively used in SI engines, are methyl alcohol, ethanol, and butanol [11–14]. Methanol can be used in SI engines to increase thermal efficiency and lower hazardous emissions [15]. Methyl Alcohol is not appropriate for broad usage as a surrogate fuel, though, because it is poisonous and can cause a major catastrophe if it seeps into the atmosphere [16,17]. Although ethyl alcohol is the most commonly utilized alcoholic fuel worldwide, prolonged utilization of ethyl alcohol in gasoline engines may cause rubber parts to expand and break, as well as deterioration of the engine's fuel system due to corrosion [18]. Isopropanol-butanol-ethanol (IBE) or acetone-butanol-ethanol (ABE) fermentation is typically used to produce biobutanol, a second-generation biomass fuel [19–22]. Although biobutanol is a better option for SI engines than ethanol or methanol regarding safety and engine longevity, butanol's high viscosity and poor evaporation properties make it unsuitable for SI engines [23]. Table 1 summarizes these additives' key fuel properties and performance aspects.

Table 1. Properties of gasoline fuel additives and performance aspects.

Properties	Gasoline [24,25]	Ethanol [24,26]	Methanol [27,28]	n-Butanol [29,30]	Isopropanol [30,31]
RON	92	108	112	92	118
Latent heat at 298 K, (kJ/kg)	380–500	904	1170	582	758
MON	78.2	90	91	85	99
Heat of evaporation at 25 °C (kJ/kg	351	919.6	1089	707.9	756.6
Oxygen content, wt%	0	34.8	50	21.6	26.6
Stoichiometric air–fuel ratio (AFR)	14.7	9.0	6.43	11.2	10.4
Density at 298 K (kg/m^3)	715–765	795	798	813	786
Auto-ignition temperature (°C)	228–470	420	465	343	399
Flash point, °C	−45	17	12	36	11.67
Carbon content, wt%	86	52.14	38	65	59.96
Boiling temperature (°C)	38–204	78	65	118	84
Hydrogen content, wt%	14	13.13	12	13.60	13.42
Lower heating value (LHV) (MJ/kg)	43.4	26.8	20.1	33.1	30.4
Laminar flame speed (cm/s)	33–44	48	48	48	45

One significant consequence of the fermentation of IBE is isopropanol. It exhibits an acetone and ethanol-like scent and is an isomer of propanol [32,33]. Because it rarely results in blindness, isopropanol is safer to use and less hazardous than methanol. It also has a greater volumetric energy density and heating value than ethyl alcohol. Compared to butyl alcohol, isopropyl alcohol possesses a greater octane rating, great evaporation characteristics, less viscosity, and more oxygen. Isopropyl alcohol is more suited for widespread use in gasoline engines since it combines the benefits of methanol, ethanol, and butanol. Nevertheless, compared to methanol, ethanol, and butanol, there is far less research on using isopropyl alcohol in engines. The majority of these studies concentrate on CI engines, with less emphasis on the utilization of isopropanol in gasoline engines.

Liu et al. [34] examined the efficiency of a turbocharged diesel engine running on various isopropyl alcohol-diesel blends with ratios of 0% to 20% volumetrically of isopropyl alcohol. The authors discovered that the addition of isopropanol greatly decreased the test diesel engine's emissions of soot and carbon monoxide. Concurrently, as the isopropyl alcohol ratio rose, the ignition time decreased, and brake-specific fuel consumption (BSFC) rose [34]. Li et al. [35] investigated the impact of the isopropyl alcohol ratio on the ignition and flame structure of spray in IBE-diesel mixtures using optical analysis. The findings showed that the spray combustion properties improved, and the soot production dramatically decreased as the isopropanol ratio rose [35]. Alptekin [36] investigated the influence of isopropyl alcohol as an additive on diesel burning and exhaust emissions. The obtained results indicated that mixtures of isopropyl alcohol and diesel had greater BSFC and ultimate cylinder pressure than pure diesel. Furthermore, the addition of isopropanol increased the concentrations of HC, CO, and NO_x [36]. Besides, Iliev et al. [37] studied the experimental influence of using isopropanol (IP) gasoline blends on a gasoline direct injection engine to examine performance and emission properties. The following gasoline and isopropanol mixtures were used in this investigation: 10% isopropanol, 20% isopropanol, 30% isopropanol, 40% isopropanol, and 50% isopropanol by volume. In comparison to net gasoline, NO_x emissions rose as the amount of isopropanol in blends increased. IP20 mixtures produced the highest NO_x emissions (405 ppm) at low engine speeds, whereas IP50 mixtures produced the highest NO_x emissions (450 ppm) at high engine speeds.

The study by Zhang et al. [38], diesel that contains isopropanol rather than gasoline would have greater particulate matter (PM) emission reduction effects [38]. The lean-burn limit of isopropyl alcohol on a petrol engine was investigated by Gainey et al. [39]. The findings demonstrated that, with an intake temperature of 320 K and an inlet pressure of 1 bar, the lean-burn limit achieved λ with an excess air ratio of 1.6. In the meantime, scientists advanced the burning phase to increase the combustion stability of isopropyl alcohol by utilizing its strong anti-knock property [39]. Additionally, Sivasubramanian et al. [40] investigated the burning and pollutant properties of mixtures of petrol and isopropyl alcohol with ratios from 10% to 30% volumetrically in a SI engine with port injection. The authors found that increasing the isopropanol ratio accelerated the rate of heat release, raised the engine's cylinder pressure, and improved its thermal efficiency; at the same time, a higher isopropyl alcohol ratio will result in NO_x pollutants rising while HC and CO pollutants falling [40]. Alcohols have several benefits, but they have a lower heating value than gasoline, which raises the engine's BSFC and allows cars to carry more fuel for the same distance [41]. However, the utilization of alcohol in engines can cause corrosion of some parts, and the corrosion caused by alcohol is harmful to engines [42–44].

The principal objective of this study is to assess how isopropanol, a sustainable and renewable gasoline additive, affects the octane performance of various gasoline constituents, such as isomerate, reformate, HSRN, and LSRN. To experimentally ascertain its impact on the RON and MON of different petrol mixtures, isopropanol is blended at different weight percentages (0–100%). Moreover, this research primarily aims to evaluate isopropanol's potential as an environmentally friendly octane enhancer that will promote the shift to cleaner energy sources while maintaining combustion stability and good fuel performance.

2. Research Methodology

This methodology allows comprehensive assessment of the effect of isopropanol on octane performance of various gasoline constituents, thereby, determine the ideal blending ratios and identify any possible fuel property trade-offs.

2.1. Materials

Figure 1 displays the experimental materials employed in this study. LSRN's higher straight-chain hydrocarbon composition results in a comparatively low RON and MON. When combined with isopropanol, both RON and MON significantly rise. The high-octane ratings of isopropanol make up for LSRN's low base octane, which enhances the fuel's anti-knock qualities under both normal and heavy load circumstances. Furthermore, HSRN has lower RON and MON because of heavier, less volatile hydrocarbons, similar to LSRN. Although isopropanol blending raises RON and MON, the effect might not be as noticeable as it would be for LSRN because HSRN already has a higher RON. Isopropanol still offers considerable advantages in high-compression engines, such as improving combustion stability and lowering knocking tendencies. Besides, isomerate has a high RON and MON since it is rich in branched paraffins. Both are significantly improved by blending with isopropanol, particularly in high-load situations. Since the addition of isopropanol increases the fuel's resistance to knocking without sacrificing other properties, the increase in MON is especially advantageous for engines that need good anti-knock performance. Additionally, reformate already has a high RON and MON due to its high aromatic content. Although the shift is less noticeable than in LSRN or HSRN, isopropanol further improves both figures. The addition of isopropanol enhances the reformate's knock resistance and combustion efficiency, making it ideal for application in premium fuels.

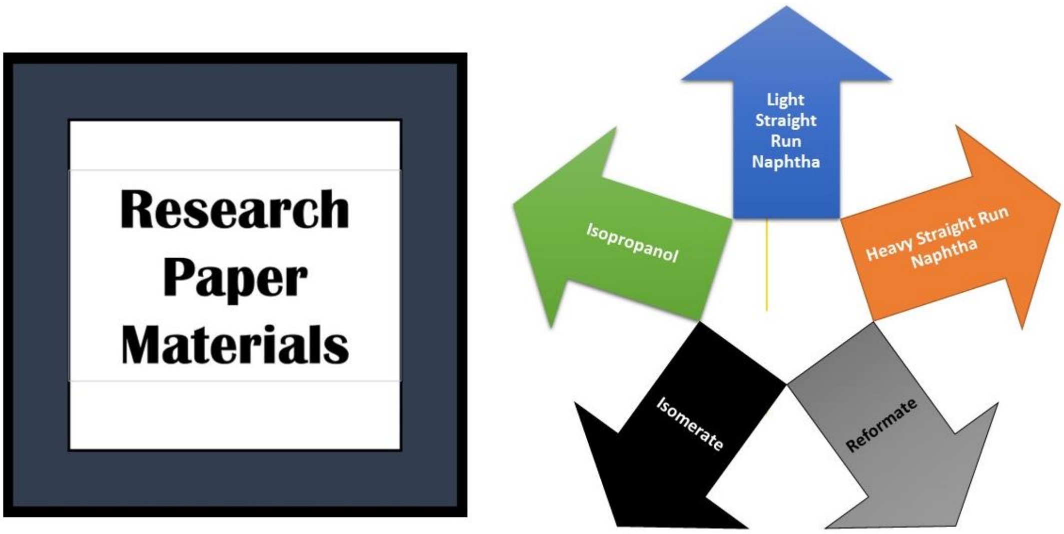

Figure 1. Research paper materials employed in this work.

2.2. Method

MON and RON for mixtures of isopropyl alcohol with studied gasoline components have been studied at 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 weight percent. By ASTM D2699, a standard research octane number test procedure was used to calculate each blend's RON. The test fuel is ignited in a test engine under compression ratios and operating settings as part of the RON test, which uses a Cooperative Fuel Research (CFR) petrol engine run under controlled conditions. Furthermore, by ASTM D2700, a standard Motor Octane Number test procedure was used to calculate each blend's MON. Like the RON test, the MON test simulates high-load driving conditions using a CFR engine in harsher circumstances, such as increased engine speed and temperature. Figure 2 shows the CFR engine test to examine RON and MON.

Figure 2. CFR engine test to examine RON and MON.

3. Results and Discussion

To prevent knocking, spontaneous combustion of the fuel for SI engines should be avoided. Octane rating and octane number are the terms used to describe the indexes utilized for gasoline burning level. MON and RON of the petrol and its mixtures were measured through experimentation in the current investigation. RON provides insights on how the petrol fuel behaves under moderate operating conditions, which are more akin to town driving (low engine temperature and speed), while the MON provides information under harsher conditions, which are more akin to highway driving (high engine temperature and speed).

The anti-knock index (AKI) is calculated as the mean of MON and RON and provides a more accurate representation of the octane rating. According to ASTM D4814, this index should be 87, modified according to the season, and used at gas station dispensers with the label (R + M)/2. Under milder and harsher settings, the AKI provides more accurate information about fuel quality. The distinction between RON and MON is the gasoline's sensitivity (S). To ensure gasoline remains stable under varying driving conditions, this value should be minimized as much as possible, particularly at $S < 10$ octane units.

Table 2 displays the computed AKI and S as well as the observed values of RON and MON in experiments for gasoline fractions and renewable and sustainable gasoline additives such as isopropanol.

Table 2. The computed AKI and S, as well as the observed values of RON and MON in experiments for gasoline fractions and renewable and sustainable gasoline additives such as isopropanol.

	IP	LSRN	HSRN	Reformate	Isomerate
RON	117	66	62	100.1	87
MON	99	62	58	83.5	83.9
AKI	108	64	60.5	91.8	85.45
S	18	4	4	16.6	3.1

3.1. Research Octane Number

Adding oxygenated components to gasoline can increase the blends' octane number. Consequently, mixing them with petrol can lessen the possibility of knocking in petrol engines. The potential of isopropyl alcohol as a sustainable octane enhancer is highlighted by the study on the influence of RON in mixtures of isopropyl alcohol with LSRN. When combined with LSR naphtha, isopropanol's high intrinsic RON can greatly increase the fuel's overall RON, making it appropriate for contemporary high-compression engines that require fuels with exceptional anti-knock properties. In addition to raising the fuel's RON, isopropanol blending enhances combustion stability and lessens knocking tendencies. The blending ratio and the baseline RON of the LSRN, however, determine how much the RON increase occurs. Although RON increases more noticeably at higher isopropanol concentrations, other characteristics such as volatility and phase stability may be affected, necessitating further tuning to suit real-world applications.

The effect of RON on the mixtures of isopropanol with LSRN is studied. Figure 3 clarifies the RON for mixtures of multiple proportions of isopropyl alcohol with LSRN. The results showed that the values of RON for mixtures of isopropyl alcohol with LSRN at 0, 10, 20, 30, 40, 50, 60,70, 80, 90, and 100 by weight percent are 66, 71.1, 76.2, 81.3, 86.4, 91.5, 96.6, 101.7, 106.8, 111.9 and 117. Furthermore, the results indicated that increasing the amount of isopropanol added to LSRN led to a higher the research octane number.

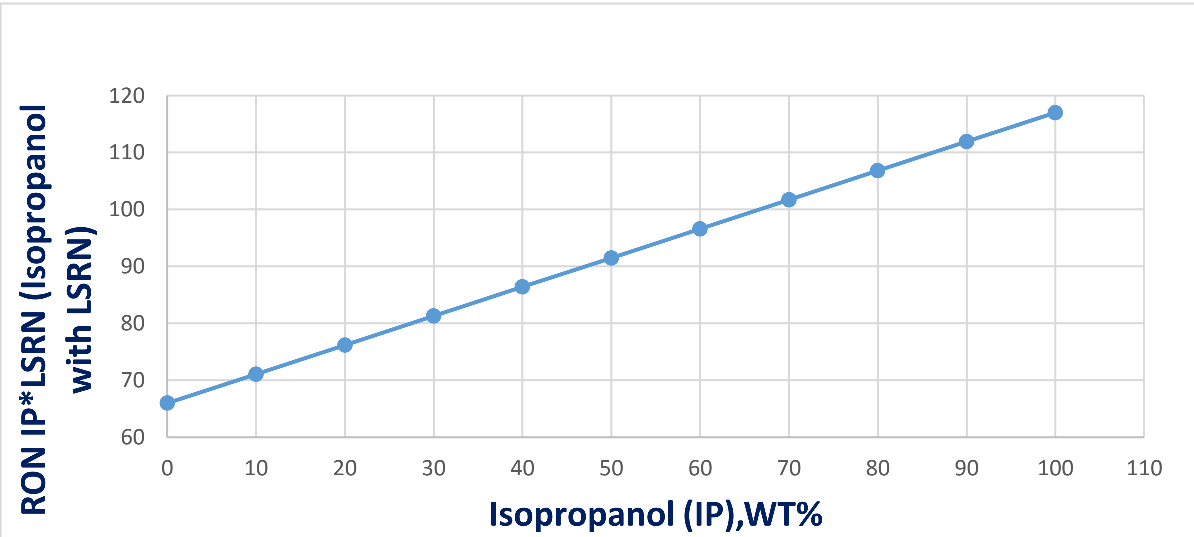

Figure 3. RON for mixtures of multiple proportions from isopropyl alcohol with LSRN.

The effectiveness of isopropanol as a high-octane addition for enhancing fuel performance is reflected by the influence of RON on mixtures of isopropyl alcohol with HSRN. For instance, addition of isopropanol, which has a high intrinsic RON, greatly improves HSRN, which can be identified based on its low RON because of its larger proportion of heavier hydrocarbons. The blending of isopropanol and HSR naphtha increases the total RON, making the blend more knock-resistant and appropriate for use in contemporary engines with greater compression ratios. However, the blending fraction and the base RON of the HSRN can affect the degree of RON improvement. Isopropanol enhances combustion characteristics, however, excessive levels can change other important fuel qualities, including density, phase stability, and distillation range. Thus, to meet the optimal fuel specifications, blend formulation must carefully balance these factors.

The effect of RON on the mixtures of isopropanol with HSRN is studied. Additionally, Figure 4 reveals the RON for mixtures of multiple proportions from isopropyl alcohol with heavy straight-run naphtha. The results reported that the values of research octane rating for mixtures of isopropyl alcohol with heavy straight run naphtha at 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 by weight percent are 62, 67.5, 73,78.5, 84, 89.5, 95, 100.5, 10, 111.5 and 117. Moreover, the results indicated that addition of more isopropanol with HSRN increased the research octane number.

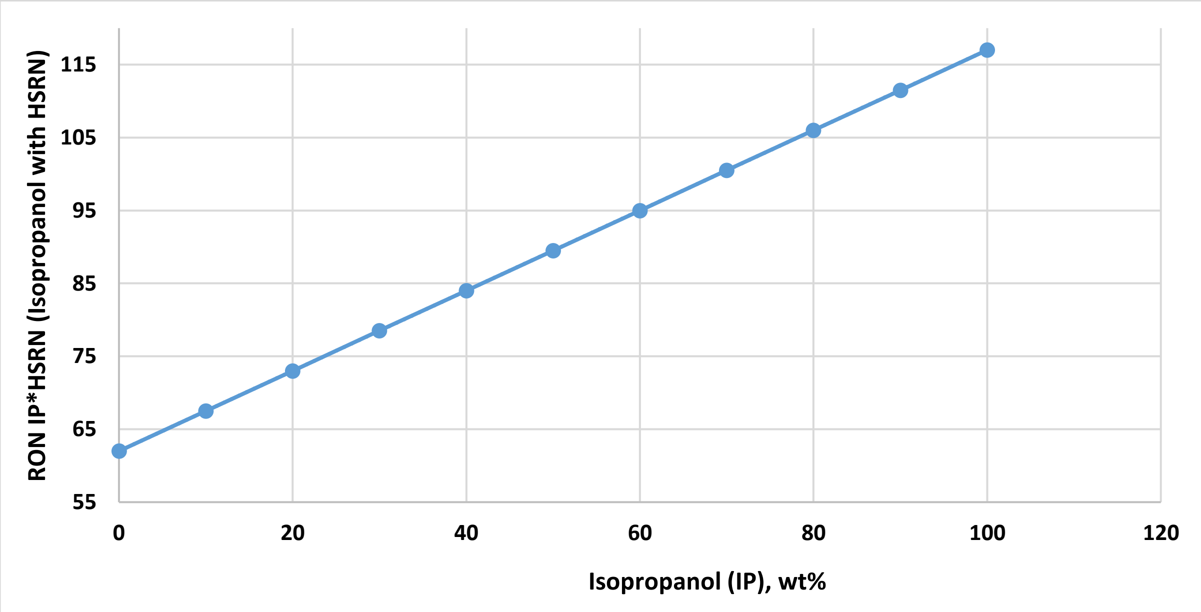

Figure 4. RON for mixtures of multiple proportions from isopropyl alcohol with HSRN.

The effect of RON on isopropanol blends containing reformate should be considered given that reformate contain a high amount of aromatic and branched hydrocarbon, which increase its RON. Isopropanol, which has a high inherent RON, is added to the blend to improve its anti-knock properties and make it appropriate for high-performance engines that need premium fuel. RON improvement in the blend depends on the amount of isopropanol used, with larger gains occurring at higher concentrations. Other characteristics, like vapor pressure, distillation curve, and phase separation risk, may be impacted by the interaction between isopropanol and reformate's aromatic content, particularly at different temperatures. To ensure that improved RON can be utilized in gasoline formulations without affecting fuel stability or violating regulatory standards, these parameters need to be optimized. The impact of RON on the mixtures of isopropyl alcohol with reformate is assessed. Furthermore, Figure 5 indicates the RON for mixtures of multiple proportions from isopropyl alcohol with reformate. The results reported that the values of Research octane rating for mixtures of isopropyl alcohol with reformate at 100, 90, 80, 70, 60, 50, 40, 30, 20, 10, and 0 by weight percent are 117, 115.3, 113.6, 113.6, 111.9, 110.2, 108.5, 106.8, 105.1, 103.4, 101.7, 100. It was also observed that adding more isopropanol with reformate resulted in increased research octane number.

The impact of RON on isopropanol and isomerate blends emphasizes the possibility of strategically blending gasoline to maximize performance. Branched paraffins make up the majority of isomerate, a high-RON gasoline component that works well with isopropanol, which also has a high RON. The blend's RON is further increased by adding isopropanol to isomerate, which also upgrades its anti-knock qualities and makes it perfect for high-compression engines. The blending ratio determines how much RON is improved; higher isopropanol concentrations result in larger improvements. However, because of their high volatility, isomerate and isopropanol together may affect the blend's volatility and Reid Vapor Pressure (RVP), necessitating careful modification to guarantee adherence to environmental regulations and fuel specifications.

The influence of RON on the mixtures of isopropyl alcohol with isomerate is explored. Figure 6 demonstrates the RON for blends of multiple proportions of isopropyl alcohol with isomerate. The results reported that the values of RON for mixtures of isopropyl alcohol with isomerate at 100, 90, 80, 70, 60, 50, 40, 30, 20, 10, and 0 by weight percent are 117, 114, 111, 108, 105, 102, 99, 96, 93, 90, and 87. Moreover, the results reported that the more isopropanol in isomerate, the more the research octane number.

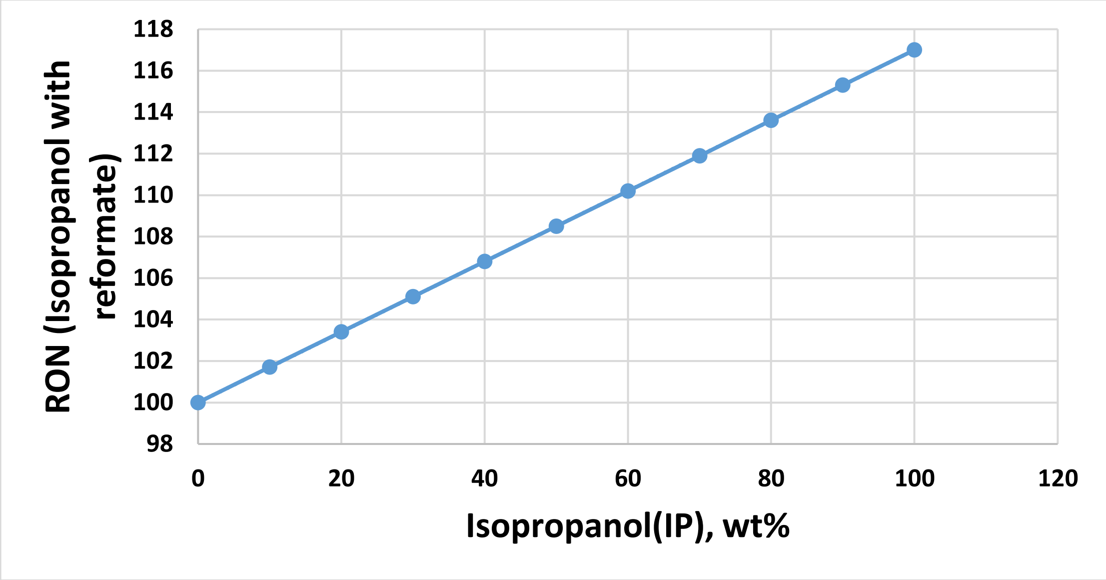

Figure 5. RON for mixtures of multiple proportions from isopropyl alcohol with reformate.

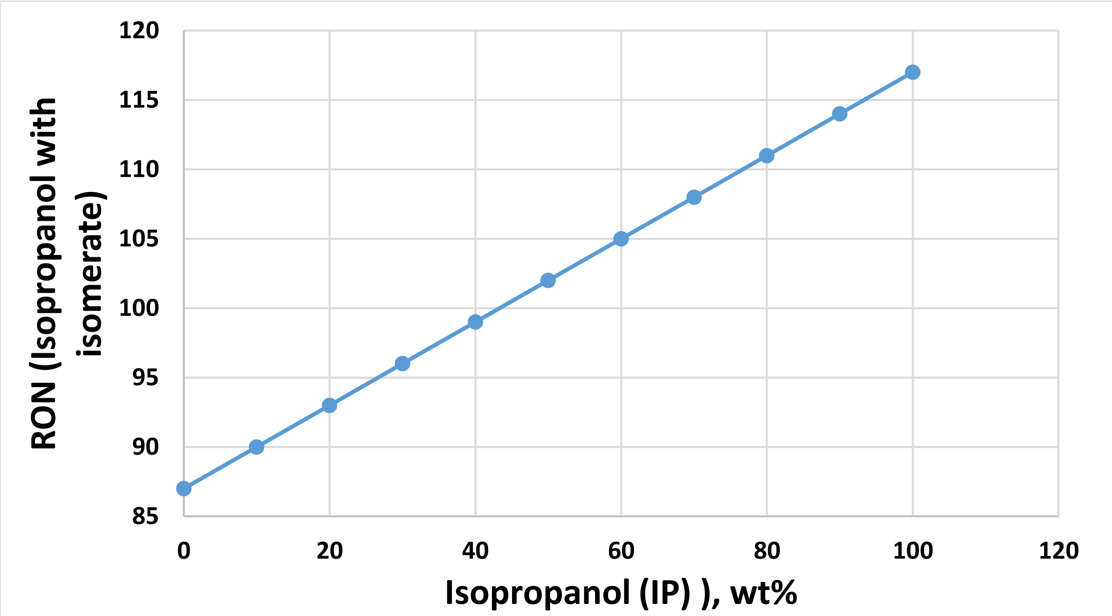

Figure 6. RON for mixtures of multiple proportions from isopropyl alcohol with isomerate.

According to the experimental findings, fuel blends' antidetonation performance, as determined by their research octane number, varies in the subsequent order: isopropanol > reformate > isomerate > LSRN > HSRN by research octane number. Isopropanol serves as an excellent additive for enhancing the anti-knock performance of gasoline blend owing to its exceptionally high intrinsic octane number. Because of its strong aromatic content, which greatly raises its octane rating, reformate comes next. Because of its intermediate octane number and branching paraffinic hydrocarbons, isomerate is a good choice for enhancing the stability of gasoline. On the other hand, LSRN and HSRN exhibit the least antidetonation performance because of their lower octane number, which is caused by a large percentage of straight-chain hydrocarbons. These findings demonstrated that isopropanol can be used to adjust fuel properties for high-compression engines, improving performance and efficiency.

3.2. Motor Octane Number

Because isopropanol has a high inherent MON, blends of it with LSRN have a much-improved MON. Because of its low MON from straight-chain hydrocarbons, LSRN performs better against knocking under high-load circumstances when isopropanol is added. The isopropanol blending ratio determines how much MON improvement occurs; higher concentrations result in larger gains. Excessive isopropanol, however, may affect the blend's phase stability and volatility, requiring careful adjustment for real-world uses. The effect of MON on the mixtures of isopropyl alcohol with LSRN is studied. Table 3 highlights the MON for mixtures of multiple proportions of isopropyl alcohol with LSRN. The results showed that the values of MONs for mixtures of isopropyl alcohol with LSRN at 100, 90, 80, 70, 60, 50, 40, 30, 20, 10, and 0 by weight percent are 99, 95.3, 91.6, 87.8, 84.2, 80.5, 76.8, 73.1, 69.4, 65.7, and 62. Furthermore, the obtained results reported that the more isopropanol was added to light straight-run naphtha, the more motor octane numbers increased.

Table 3. RON for mixtures of multiple proportions from isopropyl alcohol with LSRN.

Isopropanol (IP)	LSRN	MON IP*LSRN (Isopropanol with LSRN)
0	100	62
10	90	65.7
20	80	69.4
30	70	73.1
40	60	76.8
50	50	80.5
60	40	84.2
70	30	87.8
80	20	91.6
90	10	95.3
100	0	99

The effectiveness of isopropanol blends with HSRN is highly influenced by the MON. Due to HSRN's lower MON, attributable to its higher content of heavier, less volatile hydrocarbons—its anti-knock properties are substantially improved when blended with isopropanol. Under high-load engine conditions, isopropanol's high MON improves its combustion stability by making up for its low HSRN. The blending ratio determines the amount of MON augmentation, but too much isopropanol may change the blend's distillation range and fuel handling characteristics. This calls for careful balancing to get the desired results while still adhering to fuel regulations.

The impact of the MON on the mixtures of isopropyl alcohol with HSRN was analysed. Table 4 illustrates the MON for mixtures of multiple proportions of isopropyl alcohol with HSRN. The results revealed that the values of MONs for mixtures of isopropyl alcohol with HSRN at 100, 90, 80, 70, 60, 50, 40, 30, 20, 10, and 0 by weight percent were 99, 94.9, 90.8, 87.9, 82.6, 78.5, 74.4, 70.3, 66.2, 62.1, and 58. Furthermore, the obtained results indicated that increasing isopropyl alcohol in HSRN leads to a higher MON.

Table 4. MON for mixtures of multiple proportions from isopropyl alcohol with HSRN.

Isopropanol (IP)	HSRN	MON IP*HSRN (Isopropanol with HSRN)
0	100	58
10	90	62.1
20	80	66.2
30	70	70.3
40	60	74.4
50	50	78.5
60	40	82.6
70	30	87.9
80	20	90.8
90	10	94.9
100	0	99

The addition of isopropanol, which has a high MON, improves MON of blends of isopropanol with reformate. The addition of isopropanol improves reformate's anti-knock qualities, which makes it more appropriate for high-performance engines that run in demanding environments. Reformate, which is rich in aromatic hydrocarbons, already has a quite high MON. The amount of isopropanol in the mix determines how much MON improves; greater amounts produce a more noticeable increase. However, it's important to maintain a balanced mixture, as excessive isopropanol may adversely affect other properties, including fuel stability, vapor pressure, and volatility.

The impact of MON on the mixtures of isopropyl alcohol with reformate is evaluated. Table 5 exhibits the MON for mixtures of multiple proportions of isopropyl alcohol with reformate. The results reported that the values of MONs for mixtures of isopropyl alcohol with reformate at 100, 90, 80, 70, 60, 50, 40, 30, 20, 10, and 0 by weight percent are 99, 97.45, 95.9, 93.9, 92.8, 91.25, 89.7, 88.15, 86.6, 85.05, and 83.5. Additionally, the obtained results revealed that increasing the isopropanol content in reformate enhances the MON.

Table 5. MON for mixtures of multiple proportions from isopropyl alcohol with reformate.

Isopropanol (IP)	Reformate (R)	MON IP*R (Isopropanol with Reformate)
0	100	83.5
10	90	85.05
20	80	86.6
30	70	88.15
40	60	89.7
50	50	91.25
60	40	92.8
70	30	93.9
80	20	95.9
90	10	97.45
100	0	99

The MON on isopropanol and isomerate blends is noteworthy because both ingredients improve the fuel's anti-knock properties. Addition of isopropanol, which has a higher MON than isomerate, a fuel largely composed of branched paraffins, enhances the blend's knock resistance, particularly under high-load engine conditions. The concentration of isopropanol directly correlates with the increase in MON, with higher blends yielding more benefit. The effect of MON on the mixtures of isopropyl alcohol with isomerate was investigated. Table 6 demonstrates the MON for mixtures of multiple proportions of isopropyl alcohol with isomerate. The findings demonstrated that the values of MONs for mixtures of isopropyl alcohol with isomerate at 100, 90, 80, 70, 60, 50, 40, 30, 20, 10, and 0 by weight percent were 99, 97.48, 95.96, 94.1, 92.92, 91.4, 89.88, 88.36, 86.84, 85.32, and 83.8. Moreover, the reported outcomes increased with the addition of isopropanol into isomerate resulted in a higher motor octane number.

Table 6. MON for mixtures of multiple proportions from isopropyl alcohol with isomerate.

Isopropanol (IP)	Isomerate (I)	MON IP*S (Isopropanol with Isomerate)
0	100	83.8
10	90	85.32
20	80	86.84
30	70	88.36
40	60	89.88
50	50	91.4
60	40	92.92
70	30	94.1
80	20	95.96
90	10	97.48
100	0	99

According to the experimental findings, fuel blends' antidetonation performance, as determined by their motor octane number, varies in the subsequent order: isopropanol > reformate > isomerate > LSRN> HSRN by motor octane number. Overall, isopropanol maximizes the octane ratings of all these fuel components, with the most significant improvements seen in LSRN and HSRN due to their initially lower RON and MON, while the effect is more moderate for isomerate and reformate, which contain higher octane numbers.

4. Conclusions

The primary goal of present and future scientific study, often backed by government policies, is to promote the use of green and renewable energy for sustainable development, while avoiding environmental degradation. This research paper seeks to examine the outcome of incorporating an environmentally friendly and sustainable gasoline additive, involving isopropyl alcohol on the different blends of gasoline components, involving LSRN, isomerate, HSRN, and reformate at 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 by weight percent. The RON and MON of the petrol and its mixtures were measured through experimentation in this study.

The experimental study showed that the octane performance of different gasoline blends, such as LSRN, HSRN, isomerate, and reformate, was altered by the addition of isopropanol. Among the evaluated base fuels, isopropanol improved RON and MON due to its high RON and MON values. Since LSRN and HSRN have naturally lower octane numbers, these fuels achieved the greatest improvements, demonstrating that isopropanol exhibits comparable performance to an octane booster. The effect of isopropanol on isomerate and reformate, both containing high octane numbers, was less pronounced but still beneficial. This advantage was particularly evident in improving anti-knock performance under high-load engine conditions.

These findings demonstrate that isopropanol may serve as a renewable additive that increases the octane ratings of traditional gasoline constituents, making it ideal for maximizing fuel efficiency, particularly in contemporary high-compression engines. To ensure fuel standards, it is necessary to carefully investigate how addition of isopropanol affects other fuel characteristics, including volatility and phase stability. Future research should aim to fine-tune the blending ratios and investigate the long-term performance of these blends under actual engine settings.

The experimental findings suggested that the fuel blends' antidetonation performance, as determined by their octane number, varied in the subsequent order: isopropanol > reformate > isomerate > LSRN > HSRN by octane number. Finally, this study found that isopropanol can effectively increase RON and MON in gasoline blends. It is an environmentally-friendly substitute for traditional high-octane additives and can increase fuel efficiency and lessen engine knocking.

Author Contributions

T.M.M.A.: data curation, methodology, conceptualization, writing—original draft preparation, writing—reviewing and editing, investigation; A.M.: conceptualization, methodology, writing—original draft preparation, visualization; X.D.: conceptualization, writing—reviewing and editing, Supervision. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

Data will be available upon request.

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Conflicts of Interest

The authors declare no conflict of interest.

References

1. Gao, J.; Huang, J.; Li, X.; et al. Challenges of the UK government and industries regarding emission control after ICE vehicle bans. *Sci. Total Environ.* **2022**, *835*, 155406. https://doi.org/10.1016/j.scitotenv.2022.155406.
2. Shuai, S.; Ma, X.; Li, Y.; et al. Recent Progress in Automotive Gasoline Direct Injection Engine Technology. *Automot. Innov.* **2018**, *1*, 95–113. https://doi.org/10.1007/s42154-018-0020-1.
3. Hoekman, S.K. Biofuels in the U.S.—Challenges and Opportunities. *Renew. Energy* **2009**, *34*, 14–22. https://doi.org/10.1016/j.renene.2008.04.030.
4. Moka, S.; Pande, M.; Rani, M.; et al. Alternative fuels: An overview of current trends and scope for future. *Renew. Sustain. Energy Rev.* **2014**, *32*, 697–712. https://doi.org/10.1016/j.rser.2014.01.023.
5. Abdellatief, T.M.M.; Ershov, M.A.; Kapustin, V.M.; et al. Low carbon energy technologies envisaged in the context of sustainable energy for producing high-octane gasoline fuel. *Sustain. Energy Technol. Assess.* **2023**, *56*, 103103. https://doi.org/10.1016/j.seta.2023.103103.
6. Cardona, C.A.; Sánchez, Ó.J. Fuel ethanol production: Process design trends and integration opportunities. *Bioresour. Technol.* **2007**, *98*, 2415–2457. https://doi.org/10.1016/j.biortech.2007.01.002.
7. Das, L.M.; Gulati, R.; Gupta, P.K. A comparative evaluation of the performance characteristics of a spark ignition engine using hydrogen and compressed natural gas as alternative fuels. *Int. J. Hydrogen Energy* **2000**, *25*, 783–793. https://doi.org/10.1016/S0360-3199(99)00103-2.
8. Haldar, S.K.; Ghosh, B.B.; Nag, A. Utilization of unattended Putranjiva roxburghii non-edible oil as fuel in diesel engine. *Renew. Energy* **2009**, *34*, 343–347. https://doi.org/10.1016/j.renene.2008.03.008.
9. Göktaş, M.; Kemal Balki, M.; Sayin, C.; et al. An evaluation of the use of alcohol fuels in SI engines in terms of performance, emission and combustion characteristics: A review. *Fuel* **2021**, *286*, 119425. https://doi.org/10.1016/j.fuel.2020.119425.

10. Thaweelap, N.; Plerdsranoy, P.; Poo-arporn, Y.; et al. Ni-doped activated carbon nanofibers for storing hydrogen at ambient temperature: Experiments and computations. *Fuel* **2021**, *288*, 119608. https://doi.org/10.1016/j.fuel.2020.119608.
11. Doğan, O. The influence of n-butanol/diesel fuel blends utilization on a small diesel engine performance and emissions. *Fuel* **2011**, *90*, 2467–2472. https://doi.org/10.1016/j.fuel.2011.02.033.
12. Merola, S.S.; Valentino, G.; Tornatore, C.; et al. In-cylinder spectroscopic measurements of knocking combustion in a SI engine fuelled with butanol–gasoline blend. *Energy* **2013**, *62*, 150–161. https://doi.org/10.1016/j.energy.2013.05.056.
13. 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. https://doi.org/10.3390/en14134034.
14. Yusuf, A.A.; Inambao, F.L. Progress in alcohol-gasoline blends and their effects on the performance and emissions in SI engines under different operating conditions. *Int. J. Ambient. Energy* **2021**, *42*, 465–481. https://doi.org/10.1080/01430750.2018.1531261.
15. Balki, M.K.; Sayin, C. The effect of compression ratio on the performance, emissions and combustion of an SI (spark ignition) engine fueled with pure ethanol, methanol and unleaded gasoline. *Energy* **2014**, *71*, 194–201. https://doi.org/10.1016/j.energy.2014.04.074.
16. Jiao, J.; Li, J.; Bai, Y. Ethanol as a vehicle fuel in China: A review from the perspectives of raw material resource, vehicle, and infrastructure. *J. Clean. Prod.* **2018**, *180*, 832–845. https://doi.org/10.1016/j.jclepro.2018.01.141.
17. Yang, C.-J.; Jackson, R.B. China's growing methanol economy and its implications for energy and the environment. *Energy Policy* **2012**, *41*, 878–884. https://doi.org/10.1016/j.enpol.2011.11.037.
18. Larsen, U.; Johansen, T.; Schramm, J. *Ethanol as a Fuel for Road Transportation*; IEA: Paris, France, 2009.
19. dos Santos Vieira, C.F.; Maugeri Filho, F.; Maciel Filho, R.; et al. Acetone-free biobutanol production: Past and recent advances in the Isopropanol-Butanol-Ethanol (IBE) fermentation. *Bioresour. Technol.* **2019**, *287*, 121425. https://doi.org/10.1016/j.biortech.2019.121425.
20. Kujawska, A.; Kujawski, J.; Bryjak, M.; et al. ABE fermentation products recovery methods—A review. *Renew. Sustain. Energy Rev.* **2015**, *48*, 648–661. https://doi.org/10.1016/j.rser.2015.04.028.
21. Kumar, M.; Goyal, Y.; Sarkar, A.; et al. Comparative economic assessment of ABE fermentation based on cellulosic and non-cellulosic feedstocks. *Appl. Energy* **2012**, *93*, 193–204. https://doi.org/10.1016/j.apenergy.2011.12.079.
22. Oksal, I.N.; Kaymak, D.B. Design and control of a Biobutanol Purification Process through IBE Fermentation: Basic Design Configuration. In *Computer Aided Chemical Engineering*; Elsevier: Amsterdam, The Netherlands, 2021; Volume 50, pp. 1167–1172. https://doi.org/10.1016/B978-0-323-88506-5.50180-7.
23. Zhen, X.; Wang, Y.; Liu, D. Bio-butanol as a new generation of clean alternative fuel for SI (spark ignition) and CI (compression ignition) engines. *Renew. Energy* **2020**, *147*, 2494–2521. https://doi.org/10.1016/j.renene.2019.10.119.
24. Graham, L.A.; Belisle, S.L.; Baas, C.-L. Emissions from light duty gasoline vehicles operating on low blend ethanol gasoline and E85. *Atmos. Environ.* **2008**, *42*, 4498–4516. https://doi.org/10.1016/j.atmosenv.2008.01.061.
25. Sileghem, L.; Alekseev, V.A.; Vancoillie, J.; et al. Laminar burning velocity of gasoline and the gasoline surrogate components iso-octane, n-heptane and toluene. *Fuel* **2013**, *112*, 355–365. https://doi.org/10.1016/j.fuel.2013.05.049.
26. Veloo, P.S.; Wang, Y.L.; Egolfopoulos, F.N.; et al. A comparative experimental and computational study of methanol, ethanol, and n-butanol flames. *Combust. Flame* **2010**, *157*, 1989–2004. https://doi.org/10.1016/j.combustflame.2010.04.001.
27. Iliev, S. Investigation of the Gasoline Engine Performance and Emissions Working on Methanol-Gasoline Blends Using Engine Simulation. In *Numerical and Experimental Studies on Combustion Engines and Vehicles*; IntechOpen: London, UK, 2020. https://doi.org/10.5772/intechopen.92858.
28. MAN Energy Solutions. *The Methanolfuelled MAN B&W LGIM Engine*; MAN Energy Solutions: Copenhagen, Denmark, 2014.
29. Dutta, A. Forecasting ethanol market volatility: New evidence from the corn implied volatility index. *Biofuels Bioprod. Biorefining* **2019**, *13*, 48–54. https://doi.org/10.1002/bbb.1931.
30. Wallner, T.; Ickes, A.; Lawyer, K. Analytical Assessment of C2–C8 Alcohols as Spark-Ignition Engine Fuels. In Proceedings of the FISITA 2012 World Automotive Congress, Beijing, China, 27–30 November 2012; pp. 15–26.
31. Veloo, P.S.; Egolfopoulos, F.N. Studies of n-propanol, iso-propanol, and propane flames. *Combust. Flame* **2011**, *158*, 501–510. https://doi.org/10.1016/j.combustflame.2010.10.001.
32. Rochón, E.; Cortizo, G.; Cabot, M.I.; et al. Bioprocess intensification for isopropanol, butanol and ethanol (IBE) production by fermentation from sugarcane and sweet sorghum juices through a gas stripping-pervaporation recovery process. *Fuel* **2020**, *281*, 118593. https://doi.org/10.1016/j.fuel.2020.118593.
33. Pyrgakis, K.A.; de Vrije, T.; Budde, M.A.W.; et al. A process integration approach for the production of biological iso-propanol, butanol and ethanol using gas stripping and adsorption as recovery methods. *Biochem. Eng. J.* **2016**, *116*, 176–194. https://doi.org/10.1016/j.bej.2016.07.014.
34. Liu, Y.; Xu, B.; Jia, J.; et al. Effect of Injection Timing on Performance and Emissions of DI-diesel Engine Fueled with

Isopropanol. In Proceedings of the 2015 International Conference on Electrical, Electronics and Mechatronics, Phuket, Thailand, 20–21 December 2015; pp. 133–137. https://doi.org/10.2991/iceem-15.2015.33.
35. Li, G.; Lee, T.H.; Zhang, C. Optical investigation on impacts of component ratio on spray, combustion and flame structure of isopropanol-butanol-ethanol (IBE)/diesel blends. *Fuel* **2020**, *280*, 118602. https://doi.org/10.1016/j.fuel.2020.118602.
36. Alptekin, E. Evaluation of ethanol and isopropanol as additives with diesel fuel in a CRDI diesel engine. *Fuel* **2017**, *205*, 161–172. https://doi.org/10.1016/j.fuel.2017.05.076.
37. Iliev, S.; Ivanov, Z.; Dimitrov, R.; et al. An Experimental Investigation into the Performance and Emission Characteristics of a Gasoline Direct Injection Engine Fueled with Isopropanol Gasoline Blends. *Machines* **2023**, *11*, 1062. https://doi.org/10.3390/machines11121062.
38. Zhang, P.; Su, X.; Chen, H.; et al. Experimental investigation on NO_x and PM pollutions of a common-rail diesel engine fueled with diesel/gasoline/isopropanol blends. *Sustain. Energy Fuels* **2019**, *3*, 2260–2274. https://doi.org/10.1039/C9SE00209J.
39. Gainey, B.; Yan, Z.; Moser, S.; et al. Lean flammability limit of high-dilution spark ignition with ethanol, propanol, and butanol. *Int. J. Engine Res.* **2021**, *23*, 638–648. https://doi.org/10.1177/1468087421993256.
40. Sivasubramanian, H.; Pochareddy, Y.K.; Dhamodaran, G.; et al. Performance, emission and combustion characteristics of a branched higher mass, C3 alcohol (isopropanol) blends fuelled medium duty MPFI SI engine. *Eng. Sci. Technol. Int. J.* **2017**, *20*, 528–535. https://doi.org/10.1016/j.jestch.2016.11.013.
41. Awad, O.I.; Mamat, R.; Ali, O.M.; et al. Alcohol and ether as alternative fuels in spark ignition engine: A review. *Renew. Sustain. Energy Rev.* **2018**, *82*, 2586–2605. https://doi.org/10.1016/j.rser.2017.09.074.
42. Monteiro, M.R.; Ambrozin, A.R.P.; Santos, A.O.; et al. Evaluation of metallic corrosion caused by alcohol fuel and some contaminants. *Mater. Sci. Forum* **2010**, *636*, 1024–1029. https://doi.org/10.4028/www.scientific.net/MSF.636-637.1024.
43. Muthuraman, V.S.; Patel, A.; Shreya, V.; et al. Progress on compatibility issues of alcohols on automotive materials: Kinetics, challenges and future prospects- a comprehensive review. *Process Saf. Environ. Prot.* **2022**, *162*, 463–493. https://doi.org/10.1016/j.psep.2022.04.022.
44. Ambrozin, A.R.P.; Monteiro, M.R.; Santos, A.O.; et al. Evaluation of galvanic corrosion of a Zn alloy in alcohol fuel. *Fuel Process. Technol.* **2010**, *91*, 1687–1690. https://doi.org/10.1016/j.fuproc.2010.07.005.