Results in Engineering 26 (2025) 105347

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.sciencedirect.com/journal/results-in-engineering

Research paper

Fueling the future: Emission characteristics and sustainability of high-octane gasoline biofuels derived from lignocellulosic biomass

Tamer M.M. Abdellatief [*,a,b], Mohamed Koraiem M. Handawy [c], Amr Kamel [d], Hamada Mohamed Abdelmotalib [c], Ahmad Mustafa [e], Farrukh Jamil [a], Xiongbo Duan [f], Tareq Salameh [a], Abdul-Kadir Hamid [g], Mousa Hussein [*,h]

[a] *Sustainable Energy & Power Systems Research Centre, RISE, University of Sharjah, P.O. Box 27272, Sharjah, United Arab Emirates.*
[b] *Department of Chemical Engineering, Faculty of Engineering, Minia University, EL-Minia 61111, Egypt.*
[c] *Department of Mechanical Power Engineering and Energy, Faculty of Engineering, Minia University, EL-Minia 61111, Egypt.*
[d] *Automotive and Tractors Engineering Department, Faculty of Engineering, Minia University, EL-Minia 61111, Egypt.*
[e] *Center of Excellence, October University for Modern Sciences and Arts (MSA), Giza, 12566, Egypt.*
[f] *School of Energy Science and Engineering, Central South University, Changsha 410083, China.*
[g] *Department of Electrical Engineering, University of Sharjah, Sharjah, United Arab Emirates*
[h] *Department of Electrical and Communication Engineering, College of Engineering, United Arab Emirates University, Al Ain, United Arab Emirates.*

ARTICLE INFO

Keywords:
Gasoline Biofuel
Internal combustion engine
Renewable Energy
Lignocellulosic Biomass
Carbon-Net Zero
Sustainability

ABSTRACT

The current study demonstrates a safe and effective approach for generating gasoline biofuels RON 98 and RON 92 using light straight-run naphtha, isomerate, and reformate as base components. These biofuels are based on isopropyl alcohol, which has strong anti-detonation qualities. The impact of isopropanol as a clean, renewable, sustainable, and environmentally beneficial additive on the gasoline pool was demonstrated by analyzing the physical and chemical characteristics of the generated blends. Commercial gasoline with a rating of 92 octane and gasoline biofuel with ratings of 98 and 92 octane were compared using the exhaust emissions properties, which include carbon monoxide (CO), unburned hydrocarbons (HC), carbon dioxide (CO_2), nitrogen oxides (NOX), and oxygen (O_2). Engine speeds at which the analysis emissions were conducted were 1000, 1950, and 2650 rpm, respectively. The results of the experiment demonstrated an improvement in both the quantity and light naphtha grade. The findings reported that gasoline biofuels, particularly the 98 RON blend, reduced HC and CO emissions compared to commercial gasoline, with more significant improvements at higher engine speeds. Moreover, gasoline biofuel RON 98 showed superior fuel efficiency with the lowest specific fuel consumption and CO_2 emissions across all engine speeds. The produced gasoline biofuel 98 RON demonstrated the lowest CO emissions, with a marked drop from 1.99 % at 1000 rpm to 0.65 % at 2650 rpm. Lastly, 98 RON gasoline biofuel exhibited the highest air velocity at higher engine speeds, indicating potential improvements in engine performance under those conditions. These results suggest that gasoline biofuel RON 98 could be a cleaner and more efficient alternative to traditional gasoline, particularly in high-performance engine applications.

1. Introduction

Issues about energy and air pollution have received a lot of attention throughout the years, particularly from the automotive industry due to its significant energy consumption from fossil fuels and emissions [1], [2]. The increasing use of internal combustion engines has led to greater environmental concerns due to their emission of harmful exhaust pollutants [3]. People began to rely more on private cars for mobility as a result of their improved quality of living and diminished interest in public transportation, which caused an increase in the number of gasoline-powered cars [4],[5]. As a result, the environment is starting to suffer. Governments have lately established strict emission rules and pushed researchers to hunt for renewable fuel sources[6]. This is due to the rising consequences of global warming and the ensuing harm to human health[7]. Globally, the development of biofuels has been propelled by petroleum fuel resources and the escalating ecological problems[8],[9]. Moreover, Flex-fuel engines that run on a variety of regional or seasonal biofuels are desperately needed for sustainable

* Corresponding authors.
E-mail addresses: tamerabdellatief@mu.edu.eg (T.M.M. Abdellatief), mihussein@uaeu.ac.ae (M. Hussein).

https://doi.org/10.1016/j.rineng.2025.105347
Received 10 March 2025; Received in revised form 8 May 2025; Accepted 14 May 2025
Available online 22 May 2025

future mobility and power-generating applications[10]. Alcohols have been the subject of substantial research as alternative engine fuels among various biofuels due to their great potential for enhancing the efficiency of engines and lowering emissions from exhaust pollutants [11],[12].

Many alcohols can be mixed straight with gasoline obtained from petroleum; however, fuels with three or four carbon atoms, such as methanol[13] and ethanol[2], still have the advantageous ability to suppress combustion[14]. According to the US Department of Energy's Co-Optima project, isoalcohols and alcohols show promise based on a tiered screening technique. Because isoalcohol/gasoline blends have fewer reactive combustion intermediates and more effective radical scavenging than blends with their linear equivalents, they offer higher knock resistance[15].

Spark ignition engines have long utilized gasoline blends with alcohols; in fact, the use of alcohol with hydrocarbons has been studied since the early 1970s [16]. This is because of the enormous global requirement for hydrocarbons, which propels the world's exploitation of crude oil [17]. One of the main harmful air pollutants that endangers people is gasoline, which contains tetraethyl lead in addition to raising the octane rating. Given that alternative fuel technologies are now being tested in controlled environments, the quest to create an environment that is both pollution-free and energy-efficient is still ongoing[18]. Automotive gasoline is the finished product that is often given to the consumer at a gas station via the fuel pump. All blendstocks are included in motor gasoline, which is fully blended [19]. One of the blendstocks is isopropyl alcohol. Isopropanol is a colorless liquid that catches fire with a potent smell[20],[21]. This material yields several industrial and home compounds and is used in many industries. The first commercially available synthetic alcohol was isopropanol. Higher-order alcohols, like isopropanol, have drawn more interest lately due to their high calorific value and octane ratings.

Additionally, it is a crucial component of other compounds, including preservatives, disinfectants, and detergents. Acetone is often manufactured by hydrogenation, direct hydration, and indirect hydration [22]. Isopropyl alcohol is the most widely used and well-liked disinfectant in hospitals, clean rooms, pharmaceuticals, and medical device manufacturing [23],[24]. Isopropyl alcohol can mix with ether, water, ethanol, and chloroform[25],[26]. It dissolves various oils, alkaloids, gums, natural resins, ethyl cellulose, and polyvinyl butyral[27]. By including salt, like sodium chloride, isopropanol can be isolated from water-based solutions, unlike ethanol or methanol, which are miscible with salt solutions. Concentrated isopropyl alcohol separates into separate layers as a result of the procedure, known as "salting out." When diluted with 60 % to 90 % alcohol and 10 % to 40 % filtered water, isopropyl alcohol acts as a potent antibacterial agent against bacteria, viruses, and fungi. Table 1 summarizes these additives' key fuel properties and performance aspects.

Fig.1 illustrates the global isopropanol market trends and its forecast (2023-2029), regional analysis in 2022, and application segment overview. The market for isopropanol is projected to expand at a Compound Annual Growth Rate (CAGR) of 8.2%, from US$ 28.17 billion in 2022 to US$ 48.91 billion by 2029. This notable increase suggests that during the projection period, demand for isopropyl alcohol would rise across a number of industries. This statistic highlights the market's substantial growth potential due to its many uses, rising industrial demand, and the contributions of major international competitors. The cleaning agent and process solvent segments are anticipated to dominate its applications, while the Asia Pacific and North American regions seem to be driving market demand [38].

Only a limited number of experimental measurements have been conducted to determine the impact and advantages of C3 alcohols in SI engines. Isopropanol-n-butanol-ethanol (IBE) was combined with petrol by Li et al. [39] and conducted testing in SI engines with port fuel injection. Furthermore, IBE was mixed in different volumes (0–60 %). IBE30 performed better concerning emission properties and the efficiency of the engines, according to the experimental results. Compared to gasoline, IBE30 demonstrated increased thermal efficiency and decreased emissions of CO and NOx. Besides, Wang et al. [40] used isopropyl alcohol and isobutyl alcohol as gasoline additives in automobile gasoline and their measurement of the critical temperature and pressure. Except for the isobutanol + n-hexane system, the results indicated that the inclusion of isopropyl alcohol and isobutyl alcohol in the petrol constituents examined in the current work had a beneficial influence on the decline of the critical temperature and the increase of the necessary pressure. In an experiment, Dhamodharan et al. [41] blended gasoline and di-isopropyl ether in volumetric ratios of 30, 20, and 10 % to evaluate the engine's efficiency, emissions, and burning properties. Experiments were conducted in a four-cylinder MPFI system at 2800 rpm and 1400 rpm under two load conditions of 20 Nm and 25 Nm. Compared to gasoline, the addition of alcohol increased the cylinder pressure, heat release rate, and brake thermal efficiency. Along with a minor increase in CO_2 emissions, there were also fewer HC and CO emissions. Additionally, Goldsborough et al. [42] utilized isopropyl and isobutyl alcohols to examine the autoignition characteristics by experimental and mathematical models. It is discovered that while major ignition periods are prolonged at low temperatures, iso-alcohols reduce first-stage reactivity and the accompanying heat release.

Table 1
Properties of gasoline fuel additives and performance aspects.

Properties	Gasoline [28,29]	Ethanol [28,30,31]	Methanol [32,33,34]	n-butanol [35,36]	Isopropanol [37,36]
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

For this experiment, blends with gasoline offer sufficient control over fuel attribute fluctuation, so neat biofuels were not recommended [43]. For example, depending on the engine load requirement, the higher calorific value of gasoline may offset the smaller calorific value of these biofuels [44]. For the C1–C4 alcohol family combinations, the effect of alcohol-carbon chain length on engine burning was investigated [45]. The current work examined isopropanol because, in comparison to other propanol isomers, due to its branching structure, it has an increased octane number, which helps with upper load limit extension during engine operation.

Higher RON fuels are often better for engines built for higher compression ratios or advanced ignition timing. By enabling more

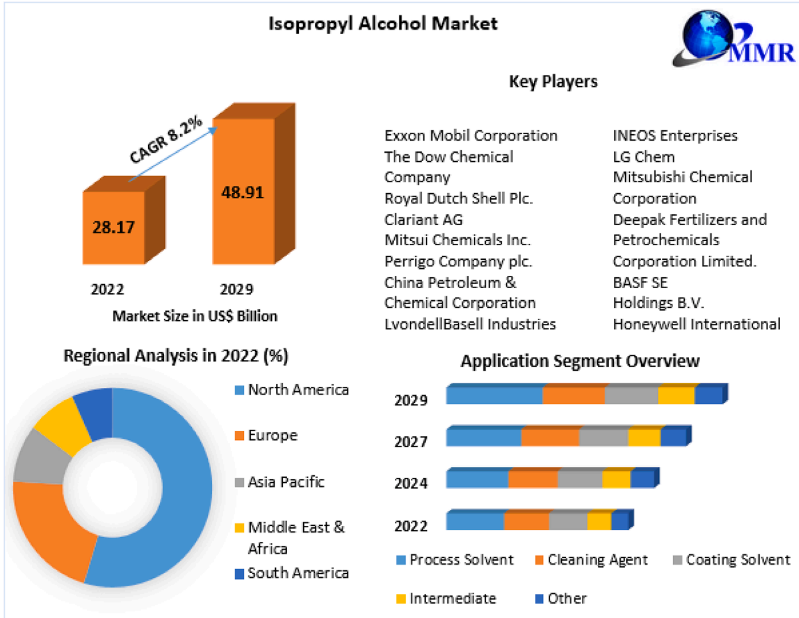

Fig. 1. Global isopropanol market trends and its forecast (2023-2029), regional analysis in 2022, and application segment overview[38].

thorough and effective combustion, the enhanced knock resistance reduces emissions of carbon monoxide (CO) and unburned hydrocarbons (UHCs) compared to lower RON fuels[46]. Higher RON fuels allow for more accurate control over the combustion process by withstanding higher pressures and temperatures without pre-ignition. The use of higher RON fuels in high-performance engines leads to cleaner exhaust emissions because of improved combustion stability. On the other hand, in high-performance engines, lower RON fuels are more likely to knock due to their lower octane content, which may result in incomplete combustion. Engines running on lower RON fuels may therefore emit more CO and HC, particularly when they are under high load. However, because ordinary or low-compression engines do not completely benefit from higher-octane fuels, the emissions variations between higher and lower RON fuels are frequently less noticeable [47].

The motivation behind this research lies in the urgent global demand for renewable energy solutions that not only reduce reliance on fossil fuels but also mitigate the environmental impacts of traditional gasoline. Therefore, the present work aims to address the growing need for cleaner and more sustainable fuel alternatives by focusing on the clean production of gasoline biofuel with high octane rating, particularly RON 98 and RON 92, based on isopropyl alcohol with high anti-detonation properties, with petroleum-based gasoline components, involving light straight-run naphtha, isomerate, and reformate. Furthermore, the physical and chemical characterizations of the produced blends were examined to illustrate the influence of isopropanol as a sustainable, clean, renewable, and eco-additive. The emissions analysis, including CO, CO_2, NO_X, O_2, and unburned hydrocarbons, was studied to make the comparison between commercial gasoline RON 92 as standard gasoline with gasoline biofuel RON 98 and gasoline biofuel RON 92. The emissions analysis was conducted at engine speeds of 1000, 1950, and 2650 rpm, respectively. Specific fuel consumption for the produced gasoline biofuel was studied. The study also investigates the specific fuel consumption of the produced gasoline biofuels, which is critical for understanding their efficiency and potential for widespread adoption. The findings from this work aim to contribute to the development of cleaner, more efficient biofuels that can be seamlessly integrated into existing fuel infrastructures, thereby offering a viable solution for reducing automotive emissions and promoting the use of renewable energy in the transportation sector.

2. Experimental campaign

The experimental setup used to measure the mechanical, chemical, environmental, and physical parameters is described in this section for generating gasoline biofuel with a rating of 98 and 92 octane based on isopropanol as oxygenated gasoline with refinery gasoline fractions, such as light straight-run naphtha.

2.1. Materials

Two gasoline blendstocks were prepared to produce gasoline biofuel RON 98 and gasoline biofuel RON 92 using bio-isopropyl alcohol from the gasification of lignocellulosic biomass, light straight run naphtha from the distillation of crude oil, isomerate from the isomerization

Table 2
Characteristics of isopropyl alcohol as a renewable and sustainable gasoline additive.

Parameter name	Value
Appearance	Colorless with a powerful odor
Research octane number	117
Motor octane number	98
The degree of cleanliness	99.9 %
Fuel density at 15 °C, kg/m^3	786 kg/m^3
Specific heat, liquid at 20 °C, J/ (kg. K)	2510.4
Latent heat of vaporization at 101.3 kPa, kJ/mol	39.8
Molecular weight	60.10
Reid vapor pressure, kPa	14.6 kPa
Boiling point at first (IBP), ^{o}C	80.5 ^{o}C
Ultimate boiling point (FBP), ^{o}C	82.5 ^{o}C
Freezing point, °C	-88.5 ^{o}C
Heat of combustion at 25 °C, kJ/mol	2005.8
Autoignition temperature, °C	399 ^{o}C
Toxicology	May cause headache, coma, and anesthesia
Flash point, oC	11.7 oC
Solubility	Soluble in water, ether, benzene, acetone, and ethanol, as well as insoluble in salt solution
Another name	Propan-2-ol, Rubbing alcohol, isopropanol, 2-propanol

process for crude oil, and reformate from the catalytic reforming process of heavy straight run naphtha. Table 2 shows the characteristics of isopropyl alcohol as a renewable and sustainable gasoline additive. Moreover, Table 3 presents the characteristics of light straight-run naphtha, reformate, and isomerate as petroleum-based gasoline fractions.

There is a lot of attention being paid to biofuels as a renewable and sustainable energy source. Isopropanol, a biofuel that belongs to the higher alcohol class (alcohols with three carbon atoms), has the potential to replace gasoline due to its superior stability, better miscibility, lower corrosivity, greater energy density, and reduced hygroscopicity in comparison with ethanol[48]. In the last ten years, numerous studies have documented effective methods for converting biomass to make these two alcohols, including metabolic engineering and synthetic biology. Fig. 2 depicts the schematic diagram of producing isopropanol as a renewable and sustainable gasoline additive. In the long run, it is anticipated that the development of less expensive feedstocks and cutting-edge technologies will make the generation of these renewable and ecologically benign bioalcohols economically viable, even though it is still necessary to overcome technical obstacles to decrease costs for generation on an industrial scale. However, because isopropyl alcohol has a higher vaporization enthalpy than gasoline, using it directly as fuel during the winter might provide difficulties for engines starting cold. Here, mixing gasoline with isopropanol could be a desirable way to enhance the fuel's qualities. According to recent studies, these mixtures may help improve engine thermal efficiency while lowering emissions of CO, NOx, and unburned hydrocarbons[18].

2.2. Methods

The work examined physical, chemical, mechanical, and ecological characteristics, including MON, gasoline octane sensitivity (S), and RON. Furthermore, emissions analysis involved CO, CO_2, NO_X, O_2, and unburned hydrocarbons to evaluate the ecological influence. besides, key petrol fuel characteristics, like benzene proportion, sulfur proportion, fuel density, vapor pressure, isopropyl alcohol proportion, aromatics content, petrol oxidation stability, and olefins concentration were also assessed. Additionally, parameters such as water inlet radiator temperature, air velocity, the corrosiveness of gasoline during the storage, existing gum, initial boiling point, final boiling point, residual in the flask during the distillation, and specific fuel consumption were examined. Fig. 3 exhibits the schematic presentation and appearance of the engine test. An engine with four strokes, four cylinders, water cooling, combined injection spark ignition, isopropanol/gasoline dual fuel, and natural aspiration was used for the experimental investigation. Table 4 summarizes the engine specification utilized for experimentation. The engine speeds when it was running were 1000, 1950, and 2650 rpm, respectively, with no load.

Table 3
Characteristics of light straight run naphtha, reformate, and isomerate as petroleum-based gasoline fractions.

Factor	Light naphtha	Reformate	Isomerate
Specific gravity	0.6699	0.8287	0.6613
Reid Vapor Pressure, kPa	85.6	15.4	92
I.B.P, ^oC	32	73	33
10 % Distilled, ^oC	44	106	41
50 % Distilled, ^oC	53	130	47
90 % Distilled, ^oC	67	170	66
F.B.P, ^oC	72	217	93
Total Sulfur, PPM	0.23	0.37	0.2
RON	66	100.1	87
MON	62	83.5	83.9
Paraffin, vol% %	85.64	22.74	86.16
Olefins, vol% %	00.00	00.45	00.00
Naphthenes, vol% %	11.45	02.43	13.83
Aromatic, vol% %	02.91	74.38	00.01

A multi-component gas analyzer system that can detect important pollutants like CO, CO_2, HC, NO_x, and O_2 was used to assess gasoline exhaust emissions precisely. A Non-Dispersive Infrared (NDIR) analyzer, which measures how much infrared light is absorbed by gas molecules, was used to test the levels of carbon monoxide and carbon dioxide. A Flame Ionization Detector (FID), which ionizes hydrocarbon molecules in a hydrogen flame and monitors the resulting ion current, was used to quantify hydrocarbons. Using a chemiluminescence detector, which produces excited NO_2 molecules that emit light proportionate to concentration when NO interacts with ozone, nitrogen oxides were examined. A paramagnetic analyzer based on the magnetic susceptibility of O_2 molecules was used to measure the oxygen concentration. To guarantee accuracy and consistency, all equipment was calibrated using approved calibration gases before testing. In order to avoid condensation and guarantee accurate identification of every species, the exhaust sample was supplied via hot pipes. The integrated system made it possible to collect data in real time and offered precise, ongoing emission level monitoring across a range of engine operating circumstances.

Additionally, Table 5 clarifies the technical specification of the gas analyzer utilized for experimentation.

2.3. Uncertainty Analysis

Uncertainty and error are inherent aspects of any experimental work and can lead to deviations from accurate measurements. In this study, most of the observed errors stem from the inherent limitations of the measuring instruments and tools used. Additionally, the use of different brands of equipment contributed to variations in the results. The current uncertainties associated with the measuring devices are summarized in Table 6.

3. Results and discussion

3.1. Physical and chemical characteristics

Because of their low sooting tendencies, oxygenated fuels have garnered attention as potential blending agents when combined with fossil fuels. Ethers, esters, alcohols, and other compounds are examples of oxygenated fuels[49]. Improved fuel efficiency, decreased emissions, decreased reliance on fossil fuels, and increased engine performance are just a few advantages of blending such oxygenates, like isopropanol, with gasoline[1],[50]. The available gasoline components should be investigated to generate gasoline of high quality with good environmental properties, in terms of preparing the optimum gasoline blend. In this regard, the authors have investigated the available gasoline components and found that the utilization of isopropanol, isomerate, reformate, and light straight-run naphtha will be potential within the production of gasoline biofuel.

Therefore, the authors made many types of gasoline biofuel blends to choose the optimal gasoline samples. Besides, Table 7 provides the composition of the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel. To estimate the quality of those optimal gasoline blends, the physical and chemical gasoline properties should be investigated. The physical and chemical properties contained RON, fuel density, octane sensitivity (S), vapor pressure, isopropyl alcohol proportion, petrol oxidation stability, olefins concentration, aromatics content, benzene proportion, sulfur proportion, the corrosiveness of gasoline during the storage, existent gum, boiling point at first, ultimate boiling point, residual in the flask during the distillation, and lead content. Table 8 displays the gasoline characteristics of marketable gasoline RON 92 and gasoline-isopropyl alcohol blends the gasoline characteristics of marketable gasoline RON 92 and generated gasoline-isopropyl alcohol blends.

One of the gasoline anti-knock quality indices, petrol octane sensitivity (S), is essential to the efficient design of next-generation spark ignition (SI) gasoline engines. The concept of the sensitivity to octane

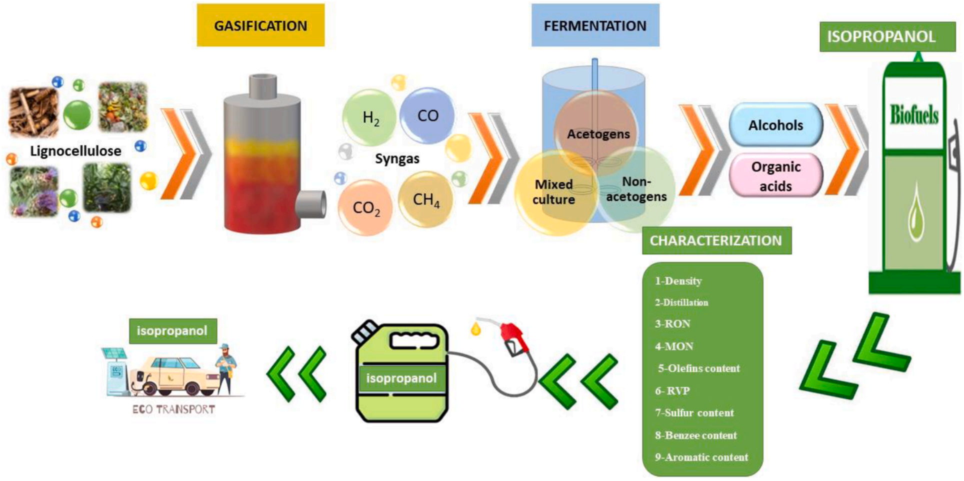

Fig. 2. Schematic diagram of producing isopropanol as a renewable and sustainable gasoline additive.

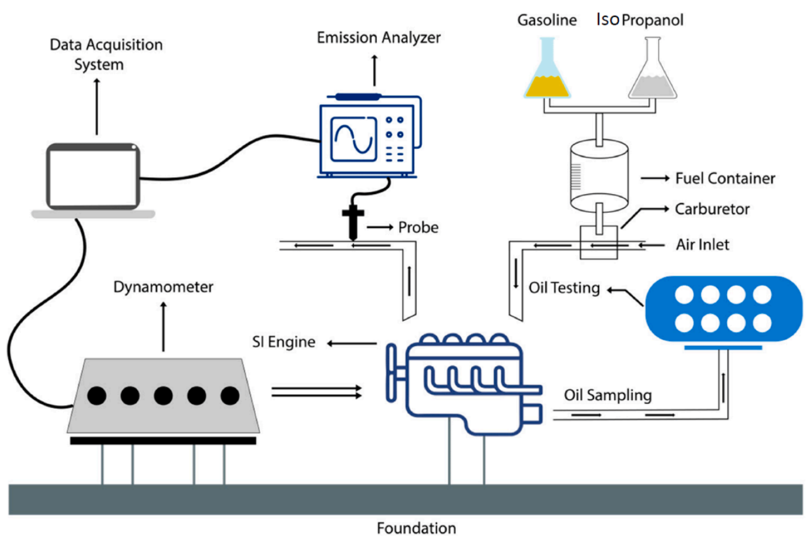

Fig. 3. Schematic presentation and appearance of the engine test.

Table 4
The engine specification was utilized for experimentation.

Type	Gasoline
Bore/ Stroke	71.5 mm/83.5 mm
Number of cylinders	4
Compression ratio	9.5
Ignition time	9^o ± BTDC
Max Torque	116.7 N.m at 3000 rpm
Maximum power	61.7 kW at 5500 rpm
Injection Fuel	Multi-Point Injection (MPI)

Table 5
Technical specification of the gas analyzer utilized for experimentation.

Empty Cell	Measuring range	Accuracy
CO_2, vol%	0–10	0.04
CO, vol%	0–20	0.1
O_2, vol%	0–25	0.4
Unburned hydrocarbon, ppm	0–10.000	20
NO_X, ppm	0–5.000	1 %

Table 6
Existing uncertainty levels of the testing equipment.

Component	Number	Uncertainty
Optical sensor	1	±100 rpm
Carbon monoxide (CO)	1	±0.1 %
Unburned hydrocarbon (HC)	1	±10 ppm
Oxygen (O_2)	1	±1 % of reading
Ambient temperature	2	±1 °C
Nitrogen oxides (NOx)	1	±10 ppm
Exhaust flow rate	1	±1.5 % of full scale
load cell	1	Accuracy tolerance of ±0.025 % of the load cell's rated output
Carbon dioxide (CO_2)	1	±0.1 %

has been presented; it is the distinction between RON and MON. But in addition to octane sensitivity and RON, other fuel-specific characteristics are also crucial for determining knock tendency, which can lead to a departure from the expected octane index. When higher pressure/temperature operation is anticipated, it has been observed that great S petrol fuels have superior anti-detonation in comparison with other fuels with identical RON and smaller S. Fig. 4 depicts the octane sensitivity for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98

Table 7
Composition of the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

Component	92 RON marketable gasoline	92 RON gasoline biofuel	98 RON gasoline biofuel
Light naphtha (LSRN)	0	30.00	17.00
Reformate (R)	40	35.00	45.00
Isomerate (I)	60	15.00	10.00
Isopropanol (IP)	0	20.00	28.00
Total	100	100	100

Table 8
Fuel properties of commercial gasoline RON 92 and produced gasoline-isopropyl alcohol blends.

Parameter	92 RON marketable gasoline	92 RON gasoline biofuel	98 RON gasoline biofuel
Appearance	Visual	Visual	Visual
RON	92	92	98
MON	84	80.2	84.2
Anti-Knock index (AKI)= (RON+MON)/2	88	86.1	91.1
S= RON-MON	8	11.8	13.8
Vapor pressure, RVP, kPa	51	47.2	34
Fuel density@15 °C, kg/m^3	745.2	746.88	772.52
Isopropyl alcohol, vol %	0	20	28
Petrol oxidation Stability	>480	>480	>480
Olefins, vol %	0.8	0.2	0.2
Aromatics, vol %	37.8	26.2	33.1
Benzene, vol %	0.9	0.1	0.1
Sulfur proportion, ppm	2.1	0.2	0.2
The propensity of gasoline to corrode when stored	Category 1	Category 1	Category 1
Existent gum, mg per 100 cm^3	1	No gum	No gum
Boiling point at first (IBP), °C	53	55	61
Ultimate boiling point (FBP), °C	183	128	142.3
Residual in flask during the distillation, %	0.8	0.7	0.6
Lead content	0.01	0.002	0.001

RON gasoline biofuel. The experimental results reported that S for produced gasoline mixtures can be ranked as the series of 98 RON gasoline biofuel >92 RON gasoline biofuel > 92 RON marketable gasoline. It was noted that the octane sensitivity for gasoline biofuel RON 98 was the highest one because it had RON of 98 and MON of 84.7, and the difference between them was 13.8. The values of the octane sensitivity for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel were 8, 11.8, and 13.8, respectively. It may be inferred that the great amount of isopropanol in the gasoline pool helps us to increase the octane sensitivity. Spark timing advance is made possible by increased gasoline octane, which also increases torque output and engine efficiency. Higher anti-knock grade gasoline can also be used to construct engines with higher compression ratios.

The degree of corrosion in gasoline is revealed by the copper corrosion test. Products made using gasoline do not experience copper corrosion in "Class 1" (1a or 1b). Because gasoline has a higher corrosion resistance than copper, a larger that one copper corrosion is not acceptable. This is typically because sulfur compounds are present in gasoline. The results reported that the corrosiveness of gasoline during storage for commercial and produced gasoline was "Class 1".

Because of environmental restrictions, the amount of benzene, olefins, and aromatics in the gasoline pool is strictly regulated. Benzene is limited to less than 1% of gasoline, olefins to less than 18%, and aromatics to less than 35%, according to the European regulations for good gasoline standards. The results indicated that the percentages of aromatics for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel were 37.8 %, 26.2%, and 33.1%, volumetrically, respectively. It can be noted that the commercial gasoline RON 92 contained a high aromatic content due to its constituent of reformate of 60 vol%. It's known that reformate, as a gasoline component, contains a high amount of aromatics. The findings reported that the aromatic content for produced gasoline blends can be ranked as the series of 92 RON marketable gasoline > 98 RON gasoline biofuel > 92 RON gasoline biofuel. The benzene content for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel was 0.9, 0.1, and 0.1, respectively. The experimental results proved that both commercial and produced gasoline were in the range of the European regulations for benzene content, which stated that the percentage of benzene should be less than 1 % volumetrically. In reference to the presence of olefins in the gasoline pool, the volumetric content of olefins in both manufactured and commercial gasoline was less than 18 percent. The olefin content for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel was 0.8, 0.2, and 0.2, respectively.

Certain kinds of hydrocarbons found in gasoline products—olefins and diolefins in particular—can slowly react with airborne oxygen during storage at room temperature[51]. Gums form because of the oxidation products that are produced[52]. The weight of residue left over after a standard volume of fuel is carefully evaporated is known as the "existent gum value," which represents the gum that is truly present in the fuel. As a precaution against storage instability, the accelerated gum test (ASTM D873, IP 138) forecasts the likelihood of gum formation during storage and the antiknock additive's breakdown. The experimental results showed that there was no existing gum in the two produced samples of gasoline biofuel RON 98 and RON 92, while the existing gum in the commercial gasoline RON 92 was 1. To determine whether gum formation could occur in the gasoline product, the oxidation stability of gasoline is tested in a lab. For a set amount of time, the gasoline sample is evaluated in an atmosphere with only oxygen.

The experimental results stated that the resistance of petrol to oxidation, concerning the induction period, was more than 480 min. The volatility of gasoline fuel affects how quickly it evaporates in the cylinder and intake channel. A good air-fuel mixture may form when the fuel volatility is low, but when the fuel volatility is great, vapor bubbles could potentially develop in the suction channel and obstruct the fuel flow when the local temperature rises. Since Reid vapor pressure (RVP) has an impact on vehicle emissions, it is a crucial criterion in the regulation of gasoline and other petroleum products. During the winter, gasoline with a higher RVP is usually used since it makes starting simpler in cold weather. Fig.5 demonstrates the Reid vapor pressure for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel. The obtained results displayed that the greater the amount of isopropanol in the sample, the lower the vapor pressure value. This was due to the low value of RVP of isopropanol in comparison with gasoline fractions, where the value of RVP of isopropanol was 14.6 kPa. The values of RVP for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel were 51, 47.2, and 34 kPa, respectively. The RVP for the 92 RON marketable gasoline was higher than the value of RVP for the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, because the 92 RON marketable gasoline did not contain isopropanol percentage, as well as this sample consisted of 60 % isomerate, where the RVP for isomerate was high (92kPa).

The many types of hydrocarbons found in gasoline can be used to assess its density. As the hydrogen content of the molecule increases, the fuel's specific mass and density decrease. In order of increasing density, paraffins, naphthenes, and aromatics are mentioned first. Fig. 6 illustrates the density at 15 °C for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel. The acquired results stated that fuel density for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel was 745.2,

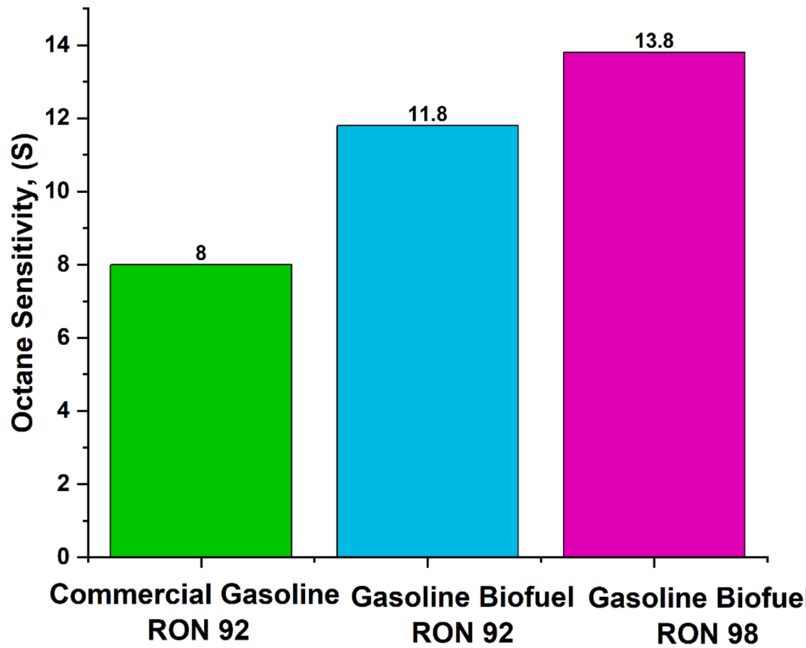

Fig. 4. Octane sensitivity (S) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

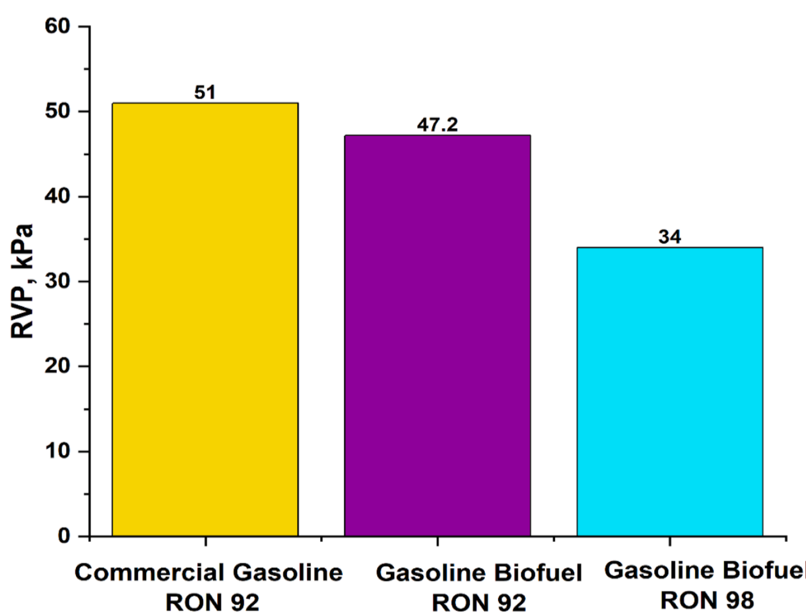

Fig. 5. Reid vapor pressure for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

746.88, and 772.52, respectively. The findings reported that the density for both commercial and produced gasoline blends can be ranked as the series of 98 RON gasoline biofuel >92 RON gasoline biofuel > 92 RON marketable gasoline.

Petrol fuel is a complicated blend of several hydrocarbons with unique characteristics[53]. As a result, when heated, various substances would evaporate at various temperatures. The fuel's distillation profile, or how much gasoline vaporizes at low temperatures, medium temperatures, and high temperatures, influences performance in a variety of ways. Initial and final boiling temperatures should be examined through the distillation properties for all produced gasoline biofuel samples. Initial boiling temperatures for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel were 53 ^{o}C, 55 ^{o}C, and 61 ^{o}C, respectively, whereas the final boiling temperature for both previous gasoline blends was 183 ^{o}C, 128 ^{o}C, and 142.3 ^{o}C, respectively. Generally, fuels with a lower boiling temperature showed reduced particle emissions, a greater flame temperature, and less visible flame.

Finally, the investigation's findings showed that both the amount and quality of light straight naphtha had improved. Moreover, with its good physical and chemical qualities, the mixed fuel of isopropanol and gasoline has a lot of potential for use as an alternative fuel. Isopropanol also possesses more advantageous qualities than commercial gasoline, such as being higher in energy content and octane number, less corrosive to engine parts, etc. For fuel application in SI engines, isopropanol hence seems more appealing than commercial gasoline. Increasing the sustainability of transportation fuels can be achieved by adding sustainable and renewable alternatives to petroleum-based fuels. For spark ignition

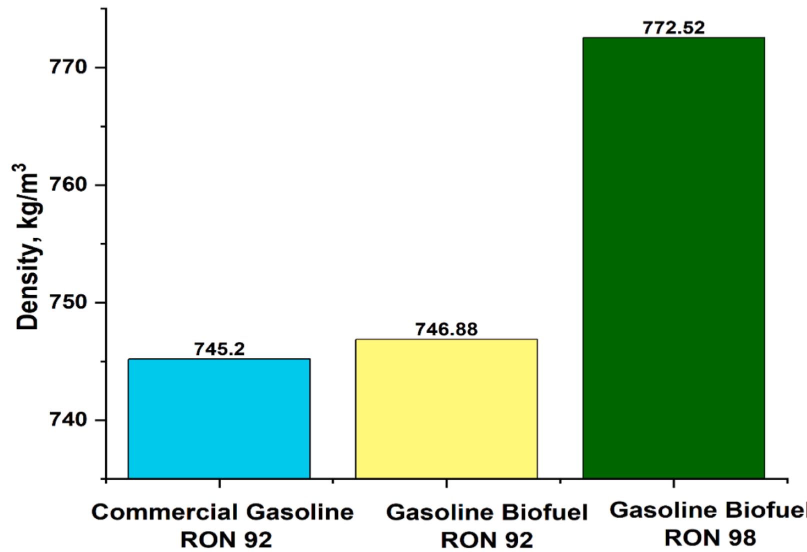

Fig. 6. Density for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

engines (SI), alcohol blendstocks are especially appealing because of their favorable fuel characteristics, which include high octane, evaporative cooling, and a decreased inclination to soot. While SI engines are widely used globally, mostly for light-duty cars, worries about carbon dioxide emissions and other sustainability issues require higher engine efficiency, fewer lifecycle carbon emissions, and reduced exhaust pollutants. One potential strategy for accomplishing these objectives is the blend of bio-isopropanol with motor fuel. Renewable alcohols can be produced in a variety of ways, including gasification and mixed alcohol fuel synthesis processes from biomass made of lignocellulosic materials, as well as fermentation from first-generation feedstocks (corn and sugar) and second-generation raw materials (biomass made of lignocellulosic materials).

3.2. Environmental and mechanical characteristics

This section examines how adding isopropanol changes the environmental discharges of O_2, HC, NOx, CO, and CO_2, water inlet radiator temperature, air velocity, water outlet radiator temperature, and specific fuel consumption. One possible partial replacement for gasoline is isopropanol. It is crucial to consider these important features to maximize the burning and environmental discharge efficiency of isoalcohol-petrol blends in engines[54]. At amounts present in ambient air, the majority of hydrocarbons do not pose a health risk [42]. Vehicle emissions change their levels, thus, it's critical to comprehend how much of them are released into the environment [55]. The result of incomplete combustion is these unburned hydrocarbons. Smog is created when the

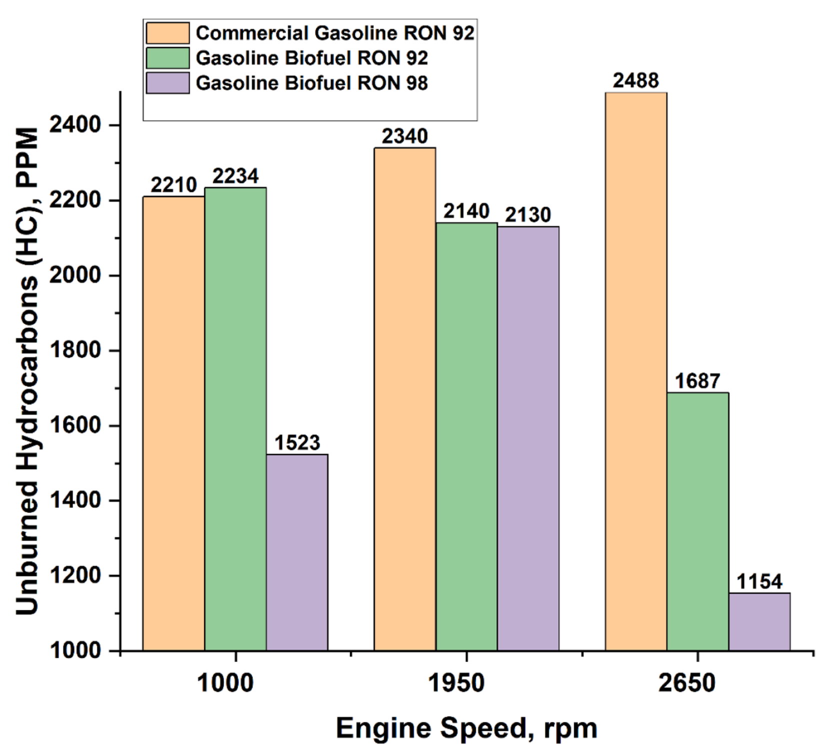

Fig. 7. Variation of unburned hydrocarbon (HC) exhaust emission against engine speed (rpm) for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

volatile organic molecules in these hydrocarbons combine with nitrogen oxides and sulfur dioxide[56]. Even a small amount of pollution exposure can occasionally result in early death and serious health issues like asthma[57].

Fig.7 demonstrates the variation of unburned hydrocarbon (HC) exhaust emission against engine speed (rpm) for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel. The engine speeds when it was running were 1000, 1950, and 2650 rpm, respectively. The results indicated that the value of unburned hydrocarbon emission at an engine speed of 1000 rpm for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel was 2210, 2340, and 2488 ppm, respectively. On the contrary, for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, the value of unburned hydrocarbon exhaust emission at an engine speed of 1950 rpm was 2234, 2140, and 1687 ppm, respectively. On the other hand, at an engine speed of 2650 rpm, the value of unburned hydrocarbon exhaust emission was 1523, 2130, and 1154 ppm for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel. The findings from the experiment demonstrated that isopropanol can reduce the environmental discharge of unburned hydrocarbons in the case of 92 RON gasoline biofuel and 98 RON gasoline biofuel as the engine speed increased. On the contrary, the value of unburned hydrocarbon emission in the absence of isopropanol in the case of 92 RON commercial gasoline increased as the engine speed increased. Furthermore, the higher the percentage of isopropyl alcohol in the gasoline pool, the lower the unburned hydrocarbon emission value. Notably, the 98 RON gasoline biofuel has the lowest HC emissions at this speed, at only 1154 ppm. When compared to regular gasoline, the results clearly showed that gasoline biofuels, particularly the higher octane 98 RON blend, dramatically reduce unburned hydrocarbon emissions. This reduction is more noticeable at higher engine speeds.

Being an oxygen-containing fuel, isopropanol can help fuels oxidize more fully by minimizing the development of localized oxygen-deficient zones in the cylinder. However, isopropanol caused the chain reaction to respond more thoroughly during combustion, releasing more OH radicals and promoting adequate fuel oxidation and combustion. In addition, a significant contributing cause to the production of unburned hydrocarbon emissions is the disruption of the chain reaction brought on by the low temperature of the combustion chamber wall. Because of the isopropanol addition during the chain reaction process, there were more OH and HO_2 radicals produced, which reduced the likelihood that the chemical reaction would be interrupted or quenched by low temperatures. Consequently, in turn, it decreased the amount of unburned hydrocarbon emissions.

Fig. 8 displays the variation of O_2 emission against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel. The results indicated that the value of O_2 emission at an engine speed of 1000 rpm for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel was 11.11, 14.20, and 15.78 % volumetrically, respectively. On the contrary, for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, the value of unburned hydrocarbon exhaust emission at an engine speed of 1950 rpm was 12.94, 13.96, and 15.63 % volumetrically, respectively. On the other hand, at an engine speed of 2650 rpm, the value of unburned hydrocarbon exhaust emission was 11.25, 10.65, and 10.11 % volumetrically for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, respectively.

The experimental result noted that the values of oxygen exhaust emission increased for both 92 RON commercial gasoline and 92 RON gasoline biofuel, while it decreased in the case of 98 RON gasoline biofuel as the engine speed increased. The value of oxygen exhaust emission was reduced in the case of 98 RON gasoline biofuel because it contained 28 % isopropyl alcohol. Finally, according to these findings, 98 RON gasoline biofuel continuously reduces oxygen emissions at increasing engine speeds, which may be a sign of more effective burning. On the other hand, 92 RON biofuel and commercial gasoline both show rising oxygen emissions as engine speed increases, which is indicative of variations in combustion behavior and operating surplus air levels.

Fig. 9 exhibits the variation of NOx emission against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel. the value of NOx emission at an engine speed of 1000 rpm for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel was 21, 65, and 50 ppm, respectively. On the contrary, the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, the value of NOx emission at engine speed of 1950 rpm was 176, 189, and 199 ppm, respectively. On the other hand, at an engine speed of 2650 rpm, the value of NOx emission was 210, 230, and 270 ppm for the 92 RON

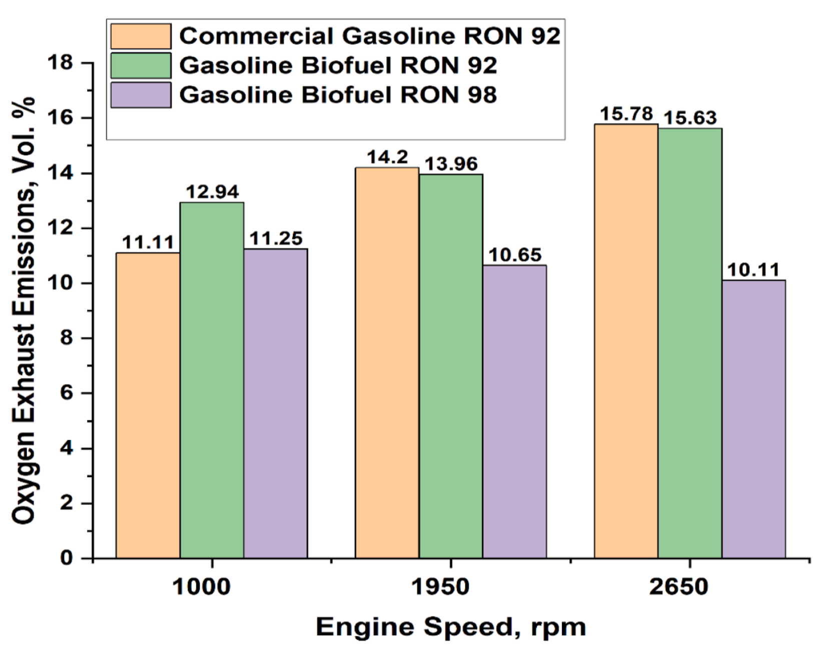

Fig. 8. Variation of O_2 emission against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

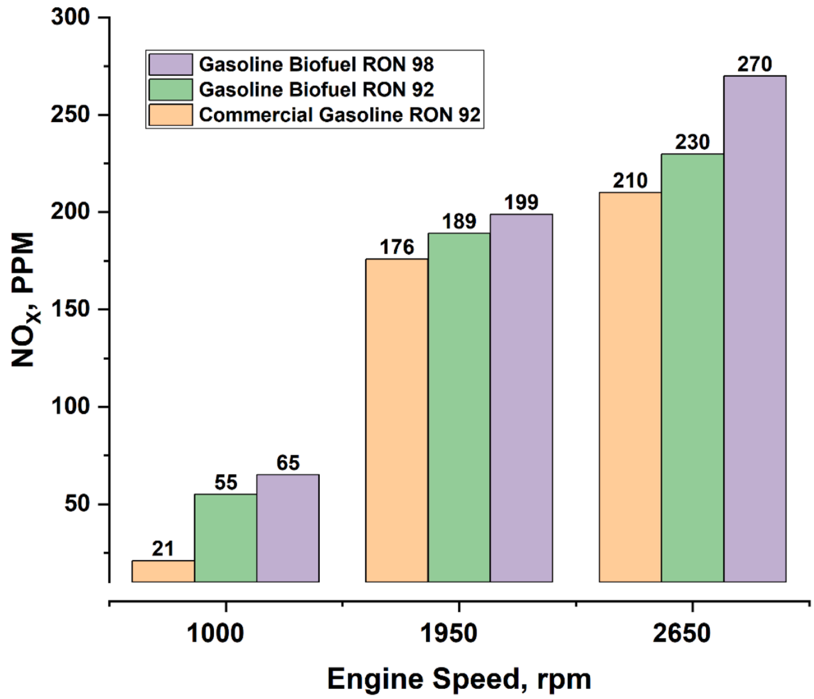

Fig. 9. Variation of NOx emission against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, respectively. The results derived from the experiments proved that adding oxygenated additives, like isopropanol, increased the NOx emissions due to the greater cylinder temperature and more oxygen supply by the additives. Furthermore, the result demonstrated that adding isopropanol to the gasoline pool can increase the NOx emissions as the engine speed increases. A catalytic converter lowers the amount of NOx emissions.

Finally, these experimental results indicated that although biofuels might have benefits in terms of oxygen and hydrocarbon emissions, they also have a tendency to produce higher NO_x emissions, particularly when engines are running at higher speeds. Increased oxygen availability and higher combustion temperatures, especially in biofuel blends, are probably the causes of the NO_x increase with engine speed.

Fig. 10 presents the variation of CO emission against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel. The experimental results exhibited that the value of CO emission at an engine speed of 1000 rpm for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel was 2.61, 1.86, and 1.99 % volumetrically, respectively. On the contrary, for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, the value of CO exhaust emission at an engine speed of 1950 rpm was 2.7, 1.92, and 1.22 % volumetrically, respectively. On the other hand, at an engine speed of 2650 rpm, the value of CO exhaust emission was 3.4, 2.26, and 0.65 % volumetrically for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, respectively. The result noted that the values of CO emissions increased for both 92 RON commercial

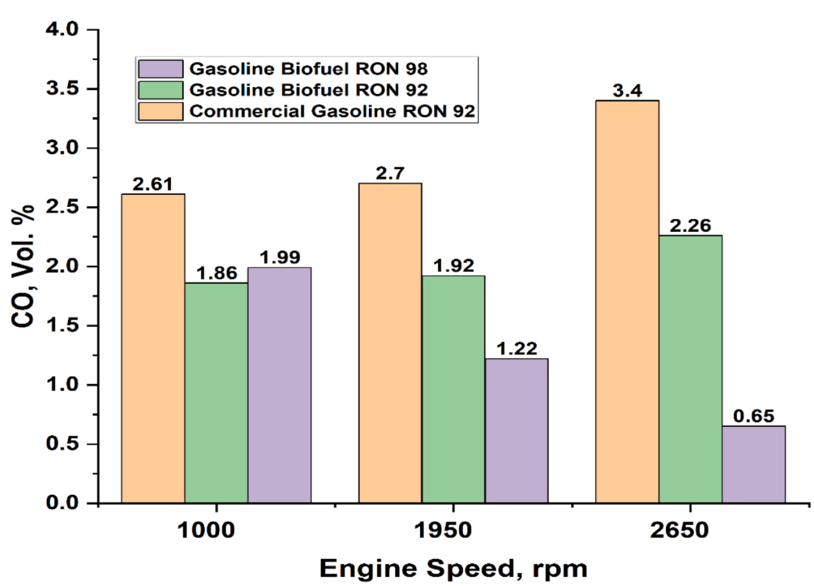

Fig. 10. Variation of CO emission against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

gasoline and gasoline biofuel, while it decreased in the case of 98 RON gasoline biofuel as the engine speed increased. The value of CO emission was reduced in the case of 98 RON gasoline biofuel because it contained 28 % isopropyl alcohol.

Finally, the cleanest alternative at higher engine speeds is gasoline biofuel RON 98, which notably shows a distinctive trend: its CO emissions begin at 1.99% at 1000 rpm and drop dramatically to 0.65% at 2650 rpm. Moreover, biofuels with higher octane ratings can considerably lower CO emissions when compared to regular gasoline, especially when engine speeds are higher.

Fig. 11 illustrates the variation of CO_2 emission against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel. The experimental results exhibited that the value of CO_2 emission at an engine speed of 1000 rpm for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel was 2.61, 1.86, and 1.99 % volumetrically, respectively. On the contrary, for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, the value of CO_2 exhaust emission at an engine speed of 1950 rpm was 2.7, 1.92, and 1.22 % volumetrically, respectively. On the other hand, at an engine speed of 2650 rpm, the value of CO_2 exhaust emission was 3.4, 2.26, and 0.65 % volumetrically for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, respectively. The obtained results indicated that the values of CO_2 exhaust emission increased for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel as the engine speed increased. Hence, the addition of isopropanol in the gasoline pool can increase CO_2 emissions as the engine speed increases.

Finally, commercial gasoline RON 92 continuously generates the greatest CO_2 emissions at all tested engine speeds, including 1000, 1950, and 2650 rpm, followed by gasoline biofuel RON 92, while gasoline biofuel RON 98 provides the lowest emissions. For all fuels, CO_2 emissions increase with engine speed, but the increase is most noticeable for biofuels, especially RON 92, which at the greatest speed almost equals commercial gasoline. The potential environmental benefit of gasoline biofuel RON 98 over both commercial gasoline and lower-octane biofuel blends is highlighted by the fact that it maintains noticeably lower CO_2 emissions across all engine speeds.

Figs. 12 and 13 show the variation of water inlet radiator temperature and water outlet radiator temperature against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel. The result noted that the values of water inlet radiator temperature increased for 92 RON commercial gasoline, while it decreased in the case of both 92 RON gasoline biofuel and 98 RON gasoline biofuel as the engine speed increased. Consequently, the incorporation of isopropanol in the gasoline pool can decrease the water inlet radiator temperature as the engine speed increases. On the other hand, the result observed that the values of water outlet radiator temperature decreased for 92 RON commercial gasoline, while it increased in the case of both 92 RON gasoline biofuel and 98 RON gasoline biofuel as the engine speed increased. Therefore, the blending of isopropyl alcohol into motor gasoline can increase the water outlet radiator temperature as the engine speed increases.

Finally, commercial gasoline RON 92 consistently exhibits the highest water inlet radiator temperatures across all engine speeds, while gasoline biofuel RON 98 shows the lowest. All fuels see an increase in temperature as engine speed rises from 1000 to 2650 rpm. Notably, the temperature difference between commercial gasoline and biofuel RON 98 is substantial, indicating better cooling performance or different heat generation characteristics for the biofuel RON 98. Additionally, for all fuels, the water outlet temperature tends to grow with increasing engine speed, albeit the amount of the increase varies; the biofuel RON 98 exhibits a lesser temperature increase than the other two fuels. In comparison to commercial gasoline RON 92 and gasoline biofuel RON 92, this implies that gasoline biofuel RON 98 may lead to efficient heat transfer or reduced total heat generation in the engine cooling system.

Fig. 14 exhibits the variation of specific fuel consumption against engine speed for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel. The obtained results exhibited that the value of specific fuel consumption at an engine speed of 1000 rpm for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel was 0.2557, 0.1705, and 0.1345 kg/hr, respectively. On the contrary, for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, the value of specific fuel consumption at an engine speed of 1950 rpm was 1.32, 0.6787, and 0.1421 kg/hr., respectively. On the other hand, at an engine speed of 2650 rpm, the value of specific fuel consumption was 2.5, 1.3443, and 0.7171 kg/hr. for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, respectively. The acquired findings suggested that the values of specific fuel consumption increased for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel as the engine speed increased. Hence, the addition of isopropanol in the gasoline pool can increase specific fuel consumption as the engine speed increases.

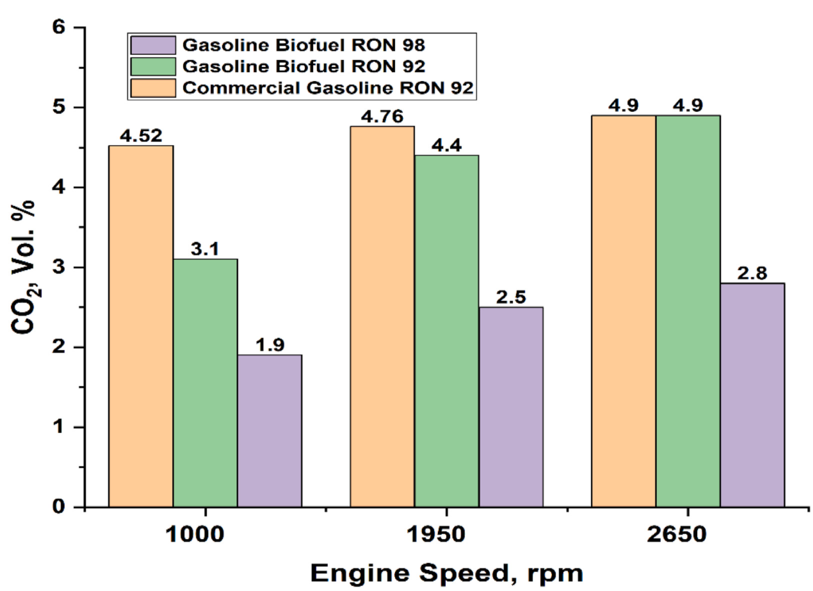

Fig. 11. Variation of CO_2 emission against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

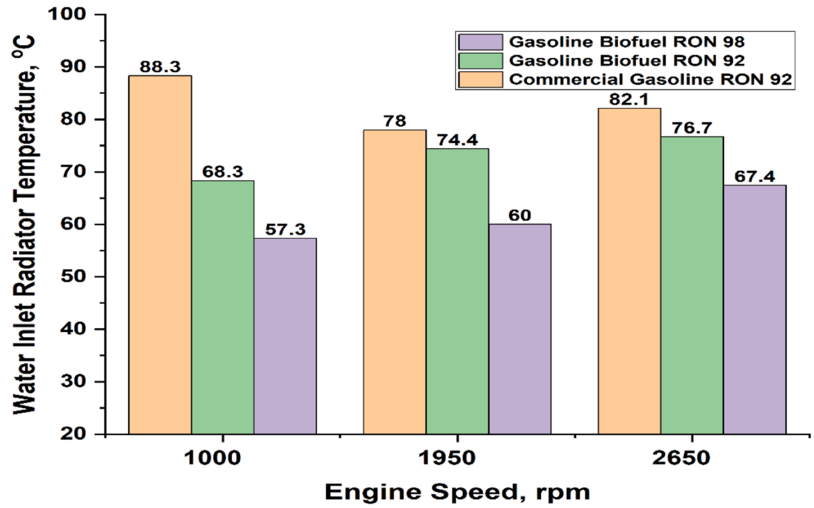

Fig. 12. Variation of water inlet radiator temperature against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

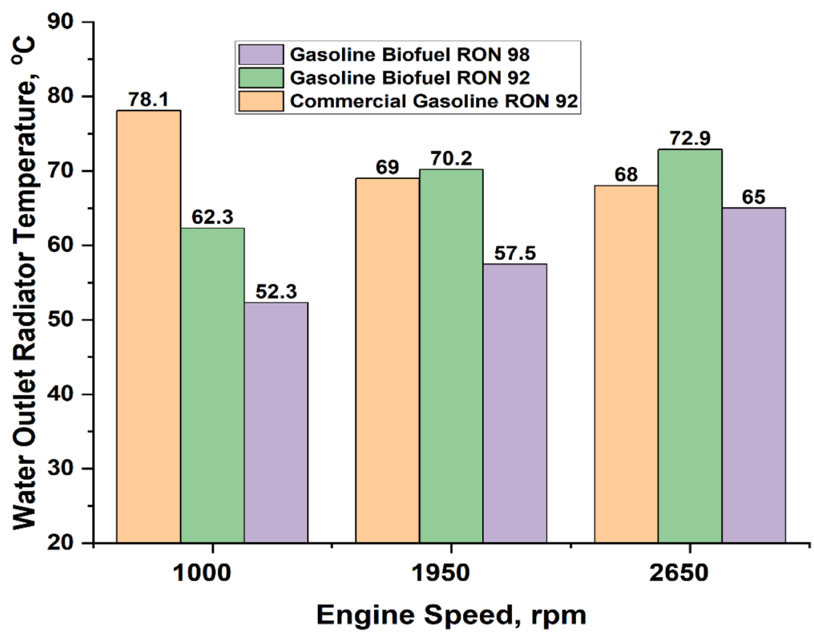

Fig. 13. Variation of water outlet radiator temperature against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

Lastly, commercial gasoline RON 92 continuously exhibits the highest specific fuel usage across all engine speeds. For commercial gasoline RON 92, the specific fuel consumption increases dramatically with engine speed, whereas it increases much less for the two biofuels. In comparison to the other two fuels, gasoline biofuel RON 98 has the lowest fuel use across all engine speeds, demonstrating superior fuel efficiency.

Fig. 15 displays the variation of air velocity (FPM) against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel. The value of air velocity at an engine speed of 1000 rpm for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel was 71.8, 102.8, and 235 FPM, respectively. On the contrary, for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, the value of air velocity at an engine speed of 1950 rpm was 491.3, 460, and 706 FPM, respectively. On the other hand, at an engine speed of 2650 rpm, the value of air velocity was 720.8, 539, and 1242 FPM for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel, respectively. The obtained results indicated that the values of air velocity increased for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel as the engine speed increased. Hence, the addition of isopropanol in the gasoline pool can increase the air velocity as the engine speed increases. In conclusion, compared to the commercial gasoline fuels 92 RON, 98 RON gasoline biofuel seems to deliver the highest air velocity at higher engine speeds, indicating that it may provide better engine performance in those circumstances.

Internal combustion engines have received a lot of attention lately due to the emergence of renewable fuels. Since isopropanol is easily made from biomass, it has long been the primary alternative fuel used to replace gasoline. In this work, light straight run naphtha, isomerate, and reformate are used to demonstrate the clean manufacture of 98 RON gasoline biofuels and 92 RON gasoline biofuels, based on isopropyl alcohol's strong anti-detonation qualities with gasoline components.

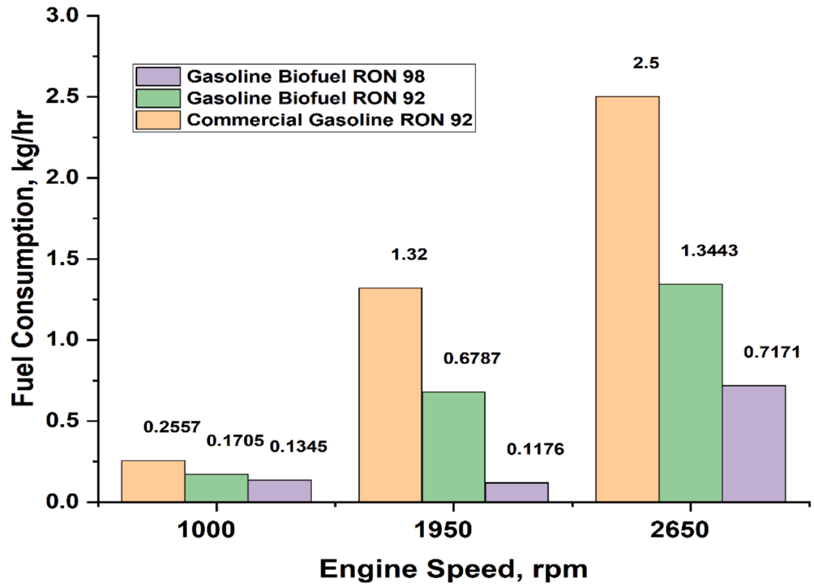

Fig. 14. Variation of specific fuel consumption (kg/hr) against engine speed (rpm) for the 92 RON commercial gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

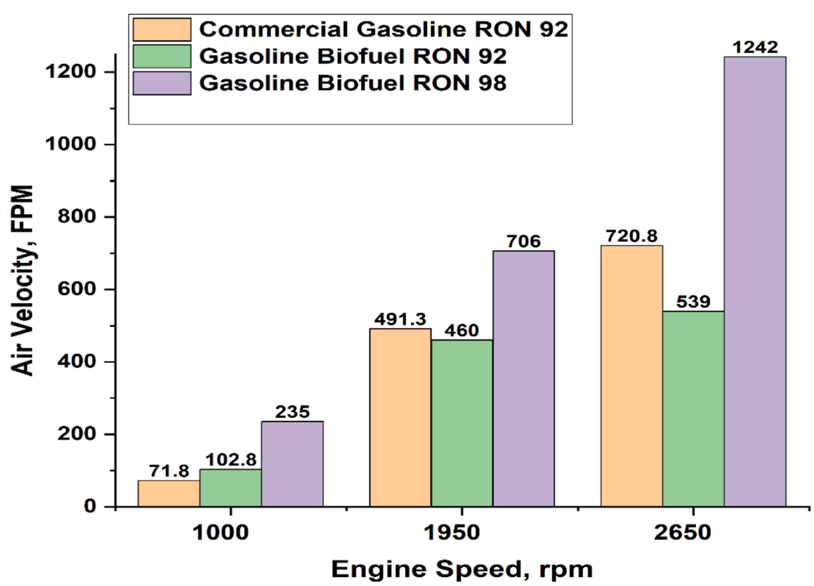

Fig. 15. Variation of air velocity (FPM) against engine speed (rpm) for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel.

Examining the physical and chemical characteristics of the resulting mixes allowed us to show how isopropanol functions as a clean, sustainable, renewable, and environmentally friendly additive.

To compare the 92 RON marketable gasoline with the 92 RON gasoline biofuel and the 98 RON gasoline biofuel, the emission analysis covering CO, CO2, NO_X, O_2, and unburned hydrocarbons was examined. Engine speeds at which the analysis emissions were conducted were 1000, 1950, and 2650 rpm, respectively. The investigation's findings showed that both the amount and grade of light naphtha had improved. The acquired findings suggested that the values of specific fuel consumption increased for the 92 RON marketable gasoline, the 92 RON gasoline biofuel, and the 98 RON gasoline biofuel as the engine speed increased. Hence, the addition of isopropanol in the gasoline pool can increase specific fuel consumption as the engine speed increases.

When compared to isopropanol-gasoline blends, isopropanol-gasoline blends had a higher potential for improving energy efficiency and lowering pollutant emissions. Isopropanol also possesses more advantageous qualities than commercial gasoline, such as being higher in energy content and octane number, less corrosive to engine parts, etc. For fuel application in SI engines, isopropanol hence seems more appealing than commercial gasoline. Lastly, the research that needs to be done is emphasized and explored to determine the ideal alcohol blend combinations and engine designs.

Finally, the physical and chemical properties of larger alcohols (C3), like energy density, miscibility, corrosivity, and water absorptivity, are more similar to those of regular gasoline. Isopropyl alcohol may now take the place of conventional fuels since they are far less hazardous. The quality, economy, and usability of isopropyl alcohol can all be improved. Even if certain fuels have problems, adding nanoparticles can fix them. It is feasible to increase isopropyl alcohol production without using renewable resources. In the future, they could prove to be beneficial endeavors.

4. Conclusion

The present work exhibits the clean production of gasoline biofuel RON 98 and gasoline biofuel RON 92 based on the isopropyl alcohol as high anti-detonation properties with petroleum-based gasoline components, involving light straight-run naphtha, isomerate, and reformate. The emissions analysis, including CO, CO_2, NO_X, O_2, and unburned hydrocarbons, was studied to make the comparison between commercial gasoline RON 92 as standard gasoline with gasoline biofuel RON 98 and gasoline biofuel RON 92, with the following conclusions achieved:

- Despite the benefits of biofuels in terms of reducing oxygen and hydrocarbon emissions, they tend to increase NO_x emissions at higher engine speeds. This is likely due to increased oxygen availability and higher combustion temperatures in biofuel blends, which contribute to the higher NO_x emissions.
- The 98 RON gasoline biofuel continuously reduces oxygen emissions with increasing engine speeds, indicating more effective combustion. In contrast, both 92 RON biofuel and commercial gasoline show rising oxygen emissions, which suggest variations in combustion behavior and surplus air levels.
- The 98 RON gasoline biofuel achieves the lowest HC emissions (1154 ppm) at higher engine speeds compared to commercial gasoline. This demonstrates that gasoline biofuels, especially the higher octane 98 RON blend, significantly reduce unburned hydrocarbon emissions, with a more noticeable reduction at higher engine speeds.
- The 98 RON gasoline biofuel exhibits the cleanest CO emissions at higher engine speeds, starting at 1.99% at 1000 rpm and dropping to 0.65% at 2650 rpm. This highlights that biofuels with higher octane ratings, particularly the 98 RON blend, can considerably lower CO emissions, especially at higher engine speeds.
- Commercial gasoline RON 92 consistently produces the highest CO_2 emissions across all tested engine speeds, followed by gasoline biofuel RON 92. In contrast, gasoline biofuel RON 98 maintains the lowest CO_2 emissions, showing a significant environmental benefit over both commercial gasoline and lower-octane biofuels.
- Commercial gasoline RON 92 exhibits the highest water inlet radiator temperatures at all engine speeds. Gasoline biofuel RON 98, however, shows the lowest temperatures, indicating better cooling performance or different heat generation characteristics. The temperature increase at the water outlet is less for biofuel RON 98 compared to commercial gasoline and 92 RON biofuel, suggesting efficient heat transfer or reduced heat generation.
- Commercial gasoline RON 92 shows the highest specific fuel consumption at all engine speeds, with a dramatic increase as engine speed rises. Both gasoline biofuels exhibit lower and more stable fuel consumption, with gasoline biofuel RON 98 showing the lowest fuel usage across all engine speeds, indicating superior fuel efficiency
- Gasoline biofuel RON 98 delivers the highest air velocity at higher engine speeds compared to commercial gasoline RON 92, indicating that it may offer better engine performance under such conditions.

The study demonstrated that 98 RON gasoline biofuel offers significant reductions in emissions and improved fuel efficiency, especially at higher engine speeds. However, the increase in NO_x emissions at elevated speeds indicates a need for further optimization. Future research should focus on refining biofuel blends to reduce NO_x emissions while maintaining performance benefits. further support the viability of gasoline biofuels, future studies should focus on long-term engine durability testing to assess wear and deposit formation. Comprehensive life cycle assessments and economic analyses are also recommended to evaluate the cost-effectiveness and environmental impact of biofuel production and use. Additionally, fuel stability and storage performance under various climatic conditions should be examined to ensure reliability across real-world applications. Additionally, exploring alternative additives or oxygenates could further enhance combustion efficiency. Overall, gasoline biofuels, particularly 98 RON, show promise as a cleaner, more efficient alternative to conventional fuels, with continued advancements needed for broader adoption.

CRediT authorship contribution statement

Tamer M.M. Abdellatief: Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Mohamed Koraiem M. Handawy:** Writing – review & editing, Validation, Project administration. **Amr Kamel:** Visualization, Resources, Investigation. **Hamada Mohamed Abdelmotalib:** Writing – original draft, Visualization, Formal analysis. **Ahmad Mustafa:** Writing – original draft, Supervision, Resources. **Farrukh Jamil:** Writing – review & editing, Methodology, Investigation. **Xiongbo Duan:** Writing – review & editing, Methodology, Conceptualization. **Tareq Salameh:** Writing – original draft, Methodology, Conceptualization. **Abdul-Kadir Hamid:** Resources, Project administration, Methodology. **Mousa Hussein:** Visualization, Funding acquisition, Conceptualization.

Declaration of competing interest

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

Acknowledgment

The authors gratefully acknowledge the technical and financial support received from the United Arab Emirates University.

Data availability

The data that has been used is confidential.

References

[1] S. Ataee, G. Rathje, F. Ramos-Pallares, The phase behavior of Isopropanol/Water/NaCl mixtures at atmospheric pressure and temperatures from 294.15 K up to the boiling point, J. Chem. Thermodyn. 189 (2024) 107205, https://doi.org/10.1016/j.jct.2023.107205.

[2] M.F. Ghazali, S.M. Rosdi, R.Mamat Erdiwansyah, Effect of the ethanol-fusel oil mixture on combustion stability, efficiency, and engine performance, Results Eng 25 (2025) 104273, https://doi.org/10.1016/j.rineng.2025.104273.

[3] A.A. Yusuf, F.L. Inambao, A.A. Farooq, Impact of n-butanol-gasoline-hydrogen blends on combustion reactivity, performance and tailpipe emissions using TGDI engine parameters variation, Sustain. Energy Technol. Assessments. 40 (2020) 100773, https://doi.org/10.1016/j.seta.2020.100773.

[4] I. Shishkova, D. Stratiev, I.V Kolev, S. Nenov, D. Nedanovski, K. Atanassov, V. Ivanov, S. Ribagin, Challenges in petroleum characterization&mdash, A Review, Energies 15 (2022), https://doi.org/10.3390/en15207765.

[5] P. Sun, X. Cheng, S. Yang, E. Ruan, H. Zhao, Y. Liu, C. Zhao, Artificial neural network models for forecasting the combustion and emission characteristics of ethanol/gasoline DFSI engines with combined injection strategy, Case Stud. Therm. Eng. 54 (2024) 104007, https://doi.org/10.1016/j.csite.2024.104007.

[6] L.O. Ajuka, R.A. Kazeem, O.A. Kuti, T.C. Jen, A.S. Afolalu, E.T. Akinlabi, Decarbonized automotive fuel: liquefied petroleum gas biosynthesis, benefits and drawbacks, Results Eng. 21 (2024) 101889, https://doi.org/10.1016/j.rineng.2024.101889.

[7] R.N. Safiullin, R.R. Safiullin, K.V Sorokin, K.A. Kuzmin, V.A. Rudko, Integral assessment of influence mechanism of heavy particle generator on hydrocarbon composition of vehicles motor fuel, Int. J. Eng. 37 (2024) 1700–1706, https://doi.org/10.5829/ije.2024.37.08b.20.

[8] A.V. Kale, A. Krishnasamy, Experimental study on combustion, performance, and emission characteristics of a homogeneous charge compression ignition engine fuelled with multiple biofuel-gasoline blends, Energy 288 (2024) 129621, https://doi.org/10.1016/j.energy.2023.129621.

[9] H. Zhu, M. Babkoor, M.-O. Coppens, M. Materazzi, Thermochemical technologies for conversion of biomass and waste into light olefins (C2-C4), Fuel Process. Technol. 267 (2025) 108174, https://doi.org/10.1016/j.fuproc.2024.108174.

[10] E.S. Rekhletskaya, M.A. Ershov, V.D. Savelenko, A.E. Makhmudova, V.M. Kapustin, T.M.M. Abdellatief, D.A. Potanin, V.A. Smirnov, T. Geng, M.A. Abdelkareem, A. G. Olabi, Unraveling the superior role of characterizing methyl ester of isohexene as an innovative high-octane gasoline mixing component, Energy Fuels 36 (2022) 11829–11838, https://doi.org/10.1021/acs.energyfuels.2c01973.

[11] F. Jamil, A. Inayat, M. Hussain, P. Akhter, Z. Abideen, C. Ghenai, A. Shanableh, T. M.M. Abdellatief, Valorization of waste biomass to biofuels for power production and transportation in optimized way: a comprehensive review, Adv. Energy Sustain. Res. 5 (2024) 2400104, https://doi.org/10.1002/aesr.202400104.
[12] Z. Zhang, J. Hu, D. Zhang, G. Jia, B. Zhang, S. Wang, W. Zhong, Z. Zhao, J. Zhang, Overview of the impact of oxygenated biofuel additives on soot emissions in laboratory scale, Fuel Process. Technol. 254 (2024) 108046, https://doi.org/10.1016/j.fuproc.2024.108046.
[13] M. Ershov, D. Potanin, E. Grigorieva, T. Abdellatief, V. Kapustin, Discovery of a high-octane environmental gasoline based on the gasoline Fischer–Tropsch process, Energy & Fuels. 34 (n.d.) 4221–4229. https://doi.org/10.1021/acs.energyfuels.0c00009.
[14] Z. Meng, F. Zhou, X. Duan, J. Fu, J. Liu, B. Deng, Experimental study of the effects of engine oil on gaseous and particulate emissions during gasoline/ethanol combustion, Fuel 386 (2025) 134331, https://doi.org/10.1016/j.fuel.2025.134331.
[15] T.M.M. Abdellatief, M.A. Ershov, V.M. Kapustin, M. Ali Abdelkareem, M. Kamil, A. G. Olabi, Recent trends for introducing promising fuel components to enhance the anti-knock quality of gasoline: a systematic review, Fuel (2021) 291, https://doi.org/10.1016/j.fuel.2020.120112.
[16] D. Stratiev, V. Toteva, I. Shishkova, S. Nenov, D. Pilev, K. Atanassov, V. Bureva, S. Vasilev, D.D. Stratiev, Industrial investigation of the combined action of vacuum residue hydrocracking and vacuum gas oil catalytic cracking while processing different feeds and operating under distinct conditions, Processes 11 (2023), https://doi.org/10.3390/pr11113174.
[17] H. Amiri, M. Tabatabaei, A.-S. Nizami, 1 - Higher alcohols: applications as fuels and chemicals, in: H. Amiri, M. Tabatabaei, A.-S.B.T.-H.A.P.P. Nizami (Eds.), Biomass and Biofuels, Academic Press, 2024, pp. 1–17, https://doi.org/10.1016/B978-0-323-91756-8.00010-4.
[18] T.M.M. Abdellatief, M.A. Ershov, V.D. Savelenko, V.M. Kapustin, U.A. Makhova, N. A. Klimov, E.A. Chernysheva, T.M. Aboul-Fotouh, M.A. Abdelkareem, A. Mustafa, A.G. Olabi, Advanced progress and prospects for producing high-octane gasoline fuel toward market development: state-of-the-art and outlook, Energy Fuels (2023), https://doi.org/10.1021/acs.energyfuels.3c02541.
[19] G.N. Palichev, D. Stratiev, S. Sotirov, E. Sotirova, S. Nenov, I. Shishkova, R. Dinkov, K. Atanassov, S. Ribagin, D.D. Stratiev, D. Pilev, D. Yordanov, Prediction of Refractive Index of Petroleum Fluids by Empirical Correlations and ANN, Processes 11 (2023), https://doi.org/10.3390/pr11082328.
[20] C. Ramírez-Márquez, J.G. Segovia-Hernández, S.S. Mansouri, 8 - Alcohol production process design and scale-up, in: H. Amiri, M. Tabatabaei, A.-S.B.T.-H.A. P.P. Nizami (Eds.), Biomass and Biofuels, Academic Press, 2024, pp. 237–269, https://doi.org/10.1016/B978-0-323-91756-8.00008-6.
[21] A. Mustafa, S. Fathy, O. Kutlu, F. Niikura, A. Inayat, M. Mustafa, T.M. M. Abdellatief, A. Bokhari, O.D. Samuel, C. Pastore, L. di Bitonto, M.A. Tawfik, M. Munir, R. Mohsen, Cleaner and sustainable synthesis of high-quality monoglycerides by use of enzyme technologies: techno-economic and environmental study for monolaurin, Clean Technol. Environ. Policy. (2023), https://doi.org/10.1007/s10098-023-02577-1.
[22] O.I. Awad, X. Ma, M. Kamil, O.M. Ali, Z. Zhang, S. Shuai, Particulate emissions from gasoline direct injection engines: A review of how current emission regulations are being met by automobile manufacturers, Sci. Total Environ. 718 (2020) 137302, https://doi.org/10.1016/j.scitotenv.2020.137302.
[23] V.G. Sharmila, S.P. Shanmugavel, J.R. Banu, A review on emerging technologies and machine learning approaches for sustainable production of biofuel from biomass waste, Biomass Bioenergy 180 (2024) 106997, https://doi.org/10.1016/j.biombioe.2023.106997.
[24] B. Chaudhry, M. Ahmad, M. Munir, M. Fawzy Ramadan, M. Munir, C. Ussemane Mussagy, S. Faisal, T.M.M. Abdellatief, A. Mustafa, Unleashing the power of non-edible oil seeds of Ipomoea cairica for cleaner and sustainable biodiesel production using green Molybdenum Oxide (MoO3) nano catalyst, Sustain. Energy Technol. Assessments. 65 (2024) 103781, https://doi.org/10.1016/j.seta.2024.103781.
[25] M.A. Asadollahi, S. Rafatiyan, M. Madadi, F. Sun, 2 - Higher alcohols: metabolic pathways and engineering strategies for enhanced production, in: H. Amiri, M. Tabatabaei, A.-S.B.T.-H.A.P.P. Nizami (Eds.), Biomass and Biofuels, Academic Press, 2024, pp. 19–65, https://doi.org/10.1016/B978-0-323-91756-8.00006-2.
[26] T.M.M. Abdellatief, M.A. Ershov, V.M. Kapustin, E.A. Chernysheva, V. D. Savelenko, T. Salameh, M.A. Abdelkareem, A.G. Olabi, Uniqueness technique for introducing high octane environmental gasoline using renewable oxygenates and its formulation on Fuzzy modeling, Sci. Total Environ. 802 (2022) 149863, https://doi.org/10.1016/j.scitotenv.2021.149863.
[27] S.U. Zhanguo, W. Zhang, A. Abdulwahab, S. Saleem, Y. Yao, A. Deifalla, M. Taghavi, Comparison of gasoline and hydrogen pathways in order to reduce the environmental hazards of a solar-hydrogen refueling station: evaluation based on life cycle cost and Well-To-Wheel models, Process Saf. Environ. Prot. 173 (2023) 317–331, https://doi.org/10.1016/j.psep.2023.03.015.
[28] L.A. Graham, S.L. Belisle, C.-L. Baas, Emissions from light duty gasoline vehicles operating on low blend ethanol gasoline and E85, Atmos. Environ. 42 (2008) 4498–4516, https://doi.org/10.1016/j.atmosenv.2008.01.061.
[29] L. Sileghem, V.A. Alekseev, J. Vancoillie, K.M. Van Geem, E.J.K. Nilsson, S. Verhelst, A.A. Konnov, Laminar burning velocity of gasoline and the gasoline surrogate components iso-octane, n-heptane and toluene, Fuel 112 (2013) 355–365, https://doi.org/10.1016/j.fuel.2013.05.049.
[30] P.S. Veloo, Y.L. Wang, F.N. Egolfopoulos, C.K. Westbrook, A comparative experimental and computational study of methanol, ethanol, and n-butanol flames, Combust. Flame. 157 (2010) 1989–2004, https://doi.org/10.1016/j.combustflame.2010.04.001.
[31] T. Abdellatief, A.-M. El-Bassiouny, T. Aboul-Fotouh, An Environmental Gasoline: Enhancing the Properties of the Gasoline Through Modified Blending Operations, Lap Lambert Academic Publishing, 2015.
[32] S. Iliev, in: P. Woś, M. Jakubowski (Eds.), Investigation of the Gasoline Engine Performance and Emissions Working on Methanol-Gasoline Blends Using Engine Simulation, IntechOpen, Rijeka, 2020, https://doi.org/10.5772/intechopen.92858.
[33] M.A.N.D. & Turbo, Using methanol fuel in the MAN B&W ME-LGI series, (2014).
[34] T.M.M. Abdellatief, M.A. Ershov, V.M. Kapustin, E.A. Chernysheva, V. D. Savelenko, A.E. Makhmudova, D.A. Potanin, T. Salameh, M.A. Abdelkareem, A. G. Olabi, Innovative conceptional approach to quantify the potential benefits of gasoline-methanol blends and their conceptualization on fuzzy modeling, Int. J. Hydrogen Energy. (2022), https://doi.org/10.1016/j.ijhydene.2022.08.076.
[35] A. Dutta, Forecasting ethanol market volatility: new evidence from the corn implied volatility index, Biofuels, Bioprod. Biorefin. 13 (2019) 48–54, https://doi.org/10.1002/bbb.1931.
[36] T. Wallner, A. Ickes, K. Lawyer, in: Analytical Assessment of C2–C8 Alcohols as Spark-Ignition Engine Fuels BT - Proceedings of the FISITA 2012 World Automotive Congress, Springer Berlin Heidelberg, Berlin, Heidelberg, 2013, pp. 15–26.
[37] P.S. Veloo, F.N. Egolfopoulos, Studies of n-propanol, iso-propanol, and propane flames, Combust. Flame. 158 (2011) 501–510, https://doi.org/10.1016/j.combustflame.2010.10.001.
[38] MMR. Isopropyl alcohol market- global industry analysis and forecast (2023-2029). https://www.maximizemarketresearch.com/market-report/isopropyl-alcohol-market/39986/. Accesseds on 22 November 2023., (n.d.).
[39] Y. Li, L. Meng, K. Nithyanandan, T.H. Lee, Y. Lin, C.F. Lee, S. Liao, Combustion, performance and emissions characteristics of a spark-ignition engine fueled with isopropanol-n-butanol-ethanol and gasoline blends, Fuel 184 (2016) 864–872, https://doi.org/10.1016/j.fuel.2016.07.063.
[40] Y. Wang, T. Lan, R. Ali, J. Xu, X. Liu, M. He, Measurement of the critical temperature and critical pressure of isopropanol and isobutanol blended with gasoline components, J. Supercrit. Fluids. 182 (2022) 105536, https://doi.org/10.1016/j.supflu.2022.105536.
[41] G. Dhamodaran, G.S. Esakkimuthu, Y.K. Pochareddy, Experimental study on performance, combustion, and emission behaviour of diisopropyl ether blends in MPFI SI engine, Fuel 173 (2016) 37–44, https://doi.org/10.1016/j.fuel.2016.01.014.
[42] S.S. Goldsborough, S. Cheng, D. Kang, C. Saggese, S.W. Wagnon, W.J. Pitz, Effects of isoalcohol blending with gasoline on autoignition behavior in a rapid compression machine: Isopropanol and isobutanol, Proc. Combust. Inst. 38 (2021) 5655–5664, https://doi.org/10.1016/j.proci.2020.08.027.
[43] O.V Săpunaru, A.E. Sterpu, M. Brînzei, S. Pascu, C.I. Koncsag, Etherification of olefins from catalytic cracking gasoline to increase its octane number, Chem. Eng. Process. - Process Intensif. 188 (2023) 109374, https://doi.org/10.1016/j.cep.2023.109374.
[44] W. Wang, W. Wang, Z. Zhu, X. Hu, F. Qiao, J. Yang, D. Liu, P. Chen, Q. Zhang, Quantitation of polyetheramines as the active components of detergent additives in gasoline by the ninhydrin reaction, Fuel 338 (2023) 127275, https://doi.org/10.1016/j.fuel.2022.127275.
[45] İ.V. Öner, A.E. Atabani, T. Durnagöl, Recycling of waste tires to crude pyrolytic oil: engine performance, combustion characteristics and emissions analysis of diesel-butanol-crude pyrolytic oil blends in CI diesel engines, Sustain. Energy Technol. Assessments. 56 (2023) 103023, https://doi.org/10.1016/j.seta.2023.103023.
[46] P. Anselmi, L. Jan, M. Matrat, G. Maio, B. Xu, Renewable fuel and blend properties for the reduction of GHG emissions under different spark-ignited engine architectures, Fuel 353 (2023) 129194, https://doi.org/10.1016/j.fuel.2023.129194.
[47] I. Abrar, T. Arora, R. Khandelwal, Bioalcohols as an alternative fuel for transportation: cradle to grave analysis, Fuel Process. Technol. 242 (2023) 107646, https://doi.org/10.1016/j.fuproc.2022.107646.
[48] D. Stratiev, I. Shishkova, R. Dinkov, S. Sotirov, E. Sotirova, K. Atanassov, S. Ribagin, R. Nikolova, A. Veli, G. Palichev, D.D. Stratiev, Do the true boiling-point distillation yields of crude oil blends obey the additive blending rule? Processes 11 (2023) https://doi.org/10.3390/pr11071879.
[49] S.M. Sarathy, P. Oßwald, N. Hansen, K. Kohse-Höinghaus, Alcohol combustion chemistry, Prog. Energy Combust. Sci. 44 (2014) 40–102, https://doi.org/10.1016/j.pecs.2014.04.003.
[50] X. Dong, Y. Guo, J. Wang, F. Xia, K. Ma, H. Duan, Z. Yang, P. Wang, M. Liang, J. Li, Novel AlCu solute cluster precipitates in the Al–Cu alloy by elevated aging and the effect on the tensile properties, Mater. Sci. Eng. A. 862 (2023) 144454, https://doi.org/10.1016/j.msea.2022.144454.
[51] V.D. Savelenko, M.A. Ershov, V.M. Kapustin, E.A. Chernysheva, T.M. M. Abdellatief, U.A. Makhova, A.E. Makhmudova, M.A. Abdelkareem, A.G. Olabi, Pathways resilient future for developing a sustainable E85 fuel and prospects towards its applications, Sci. Total Environ. (2022) 157069, https://doi.org/10.1016/j.scitotenv.2022.157069.
[52] F. Jamil, A review on biodiesel production, analysis, and emission characteristics from non-edible feedstocks, ChemistrySelect. 8 (2023) e202300800, https://doi.org/10.1002/slct.202300800.
[53] T.M.M. Abdellatief, M.A. Ershov, V.M. Kapustin, E.A. Chernysheva, V. D. Savelenko, T. Salameh, M.A. Abdelkareem, A.G. Olabi, Novel promising octane hyperboosting using isoolefinic gasoline additives and its application on fuzzy

modeling, Int. J. Hydrogen Energy. 47 (2022) 4932–4942, https://doi.org/10.1016/j.ijhydene.2021.11.114.
[54] I. Veza, M. Spraggon, I.M.R. Fattah, M. Idris, Response surface methodology (RSM) for optimizing engine performance and emissions fueled with biofuel: Review of RSM for sustainability energy transition, Results Eng. 18 (2023) 101213, https://doi.org/10.1016/j.rineng.2023.101213.
[55] A. Elfasakhany, Engine performance evaluation and pollutant emissions analysis using ternary bio-ethanol–iso-butanol–gasoline blends in gasoline engines, J. Clean. Prod. 139 (2016) 1057–1067, https://doi.org/10.1016/j.jclepro.2016.09.016.
[56] D. Li, X. Yu, Z. Guo, J. Zhang, T. Wang, Y. Li, Effects of isopropanol ratio at different excess air ratios on combustion and emissions characteristics of an isopropanol/gasoline dual-fuel combined injection SI engine, Fuel 333 (2023) 126507, https://doi.org/10.1016/j.fuel.2022.126507.
[57] A.V. Kale, A. Krishnasamy, Experimental study of homogeneous charge compression ignition combustion in a light-duty diesel engine fueled with isopropanol–gasoline blends, Energy 264 (2023) 126152, https://doi.org/10.1016/j.energy.2022.126152.