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Effect of Blending Aromatic and Oxygenates Additives with Fuels to Enhance Fuel Properties

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ABSTRACT

This work aims to show the influence of several oxygenates and aromatic additives in different types of unleaded fuels in the Kurdistan region of Iraq on upgrading the physicochemical properties of blends. Consuming super-grade gasoline as a fuel for automotive cars can produce large amounts of environmental emissions, a severe global problem, especially in the Kurdistan region in recent years. The physicochemical properties of mixtures, such as the research octane number (RON), Motor Octane number (MON), density, and distillation curves, will be tested by using ERASPEC spectroscopy as a fuel properties analyzer. As a result, the blending process has improved the gasoline grade to super grade by enhancing the physicochemical properties of blends. The additives used in this work as oxygenators are; Ethanol and Methyl Tertiary Butyl Ether (MTBE) added to two base fuels, light Naphtha, and unleaded Gasoline, in various ratios of (5%, 10%, 15% and 20%). An aromatic component (Aniline) is also mixed with light Naphtha and base gasoline in low concentrations (1%, 3%, and 5%). The results of blending Ethanol, MTBE, and Aniline with fuels demonstrate that the Research Octane Number (RON) and Motor Octane Number (MON) of fuels increase with the addition of different ratios of all-octane boosters. The best-recorded result of both types of octane numbers (13 points increased from the bases) is recorded by blending 3% of Aniline with the fuels. However, Ethanol can provide a more significant increase in RON and MON than Methyl Tertiary Butyl Ether (MTBE) for the same blending ratio. The Density of the mixtures also increases because both additives have a higher density than the fuel due to the presence of different hydrocarbon compounds. The mixture's distillation curves are distorted, especially when the low to the middle percent of blenders are added to fuels. However, higher percentages of additives show lower distillation temperatures.

Keywords: Gasoline, Light Naphtha, Chemical additives, Research Octane number, Motor Octane number, Density, distillation curve.

1. Introduction

One of the serious environmental problems in recent decades is the emission of a high level of greenhouse gases in internal combustion machines. The main reason for that is the partial combustion of carbonaceous fuels in them [1]. There are several consequences of incomplete fuel combustion, such as: producing carbon monoxide (CO), creating specific soot, and producing nitrogen or sulfur oxides[1]. In addition, the rate of producing these pollutants is related to the operating conditions and the ratio of fuel/air [1, 2]. In recent decades, gasoline has been one of the most common fuels used to ignite the internal combustion engine[2]. Gasoline is a mixture of volatile liquids as it contains several hydrocarbon compounds with a boiling point temperature of 355– 390 ºF)[3]. Therefore, gasoline is produced from either crude oil distillation (atmospheric and vacuum) or different processing of petroleum's feedstock (reforming, Alkylation, and others)[1, 2, 3].

Gasoline can burn in the internal combustion engine because of its ability to blend quickly with air and is also used as a solvent to remove oils and fats[3]. Gasoline must be evaporated by mixing it with air (oxygen) to change its phase from liquid to gas and ignite in the automotive engine[4]. The chemical composition of gasoline is different based on the processes of refining and the type of petroleum that is derived from[3, 4]. The typical hydrocarbon compounds that are found in gasoline are alkanes (4-8 vol. %), alkenes (2-5 vol. %), Benzene (0.5-2.5 vol. %), Cycloalkanes (3-7 vol. %), Cycloalkanes (1-4 vol. %), iso-alkanes (25-40 vol. %) and total aromatic (20-50 vol. %) that all their molecular chains contain 4-12 carbon atoms. They are organized in the range of gasoline fuel[3, 5].

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Nowadays, numerous artificial components can also be added to automotive fuels to improve fuel performance and meet the demand for advanced engine technology[6, 7, 8]. It is mentioned (Hamadi 2010) that the base method of producing different kinds of gasoline is blending proper components with the designated feedstock of hydrocarbons[9]. In addition, the hydrocarbons' feedstocks that increase the yield of gasoline are achieved from the primary separation, catalytic cracking, thermal cracking, hydrocracking, Alkylation, polymerization, coking, isomerization, and other refinery units which blend antiknock agent stock with gasoline to produce the required amount of high-octane gasoline[9]. Consequently, different grades of gasoline are produced, and they can be divided into superior and regular grades and other various types in several countries based on their octane number[2, 9].

Combusting the mixture of air-fuel in the engine's cylinder can make a pinging, and severe sound called knocking, which can be very risky for the engine and reduce its efficiency[10]. One of the gasoline's most significant supreme features is its octane number, which measures the knock resistance property of gasoline in the internal combustion engine[4, 10]. Furthermore, the Octane Number (ON) is also defined by (Abid et al., 2013) as a standard measure of fuel's performance (aviation fuel or automotive fuel) under different operating conditions of the engine [11]. Thus, the Optimal Octane number must be met and specified in the produced gasoline[1, 8]. Fuels with a high octane number are indicated as high compression fuel. It is used in the high-compression motors that need a high octane number fuel because those motors are generally indicated as developed performance motors[11, 12]. According to (Boot, 2017), (Abid, et, al. 2013), and (Nibal, 2014), one of the gains of enhancing the octane rating of fuel is the reduction of emissions gases in the environment and consequently knocking of the engine will be reduced[10, 11, 12]. Another benefit of enhancing the octane number mentioned by previous literature is the improvement of the engine's cold starting, which can recover the engine's strength[10, 11,12].

Different types of octane numbers are measured as Research Octane Numbers (RON) and Motor Octane Numbers (MON)[13]. A test engine with a different compression ratio can be run to measure the Research Octane number (RON) of fuel under controlled situations. The results can be compared with the RON of mixtures of n-heptane and iso-octane[8, 11]. The second type of octane number is Motor Octane Number (MON), also called aviation poor octane rating[13]. Furthermore, MON is applied to measure the octane rating of a fuel under a load to know better how the fuel behaves under the load[13]. Because of that, MON is measured at 900 rpm of the engine speed; however, RON is measured at 600 rpm of the engine speed[11, 13]. The measurement of MON and RON can be recorded by using the CFR F1/F2 octane rating machines that are specified for testing fuels according to a standard test method of ASTM D2700 for MON of engine fuel and a standard test method of ASTM D2699 for RON of Engine fuel[13, 14]. A digital apparatus, ZX 101 XL, is also used to measure both MON and RON of engine fuel together[14]. A modern apparatus of fuel analyzer, which is ERASPEC spectroscopy, has been developed to study the properties of gasoline in terms of its oxygenates, aromatics, Octane boosters, Research Octane Number (RON), Motor Octane Number (MON), Density, distillation curve, and Raid Vapor Pressure (RVP)[14].

Over the last eight decades, producing fuels have improved continuously due to the development of different petrochemical methods. The main reason for that is increasing the demand of using the amount of gasoline and having a great demand on the gasoline resistance for knocking simultaneously[15]. Today, a super grade of gasoline with high resistance to knocking is mainly used as internal combustion engine fuel; therefore, adding various oxygenators or other materials to reformulate the fuels' molecule structure can make it easier to achieve the aim [15]. The most extensive resource of the antiknock agent mentioned by (Hamadi, 20100) and (Seyferth, 2003) was organometallic compounds that include methylcyclopentadienyl manganese tricarbonyl (MMT) and tetra Ethyl lead (TEL)[9, 16]. These materials can offer high-octane number boosting and antiknock specification, making them attractive for fuel marketers and refineries. The results of several kinds of research claimed that mixing lead with gasoline increased the number of octane fuels the past years ago[1, 2, 16]. However, environmental pollution is the most severe problem related to adding those agents to gasoline because they are very toxic materials and are not environmentally friendly. Thus, tetraethyl lead has been prohibited in almost all countries[1, 2, 16].

Other selective materials, including oxygenates, alkylate, aromatic, isomerate, and light or heavy aliphatic hydrocarbons, have been discussed as agents to reduce the knocking of the engine as a result of mixing them in an appropriate amount with gasoline instead of the restricted lead[8, 9, 14, 15, 16, 17]. Mixing a different ratio of those additives with gasoline can affect its elemental composition. Consequently, several gasoline's Petrophysical properties, such as vapor pressure, distillation curve, density, and octane rating, will be altered[3, 7]. However, the main aims of the addition are to reduce the emission of pollutant gases from the vehicle and to reduce the rate of knocking in the automotive engine[14].

Numerous applicable specifications can be attained as a result of adding oxygenates to gasoline, and they are indicated as follows: hydrocarbon combustion is almost completed in the engines, then the emission of carbon monoxide (CO) is reduced in the wintertime, and reducing smog in summer time[1, 2, 12]. Oxygenated additives are antiknock agents for unleaded fuels; thus, the octane rating and volatility of the fuels will be enhanced[12]. Particular Renewable agricultural raw materials (corn) are the source of producing oxygenate, such as Ethanol, so that they can be a renewable energy source instead of fossil fuel[1, 12]. On the other hand, adding oxygenates to gasoline can have several drawbacks that include recording an increase in the cost and the volatility properties of fuel[1, 8]. The automotive engine faces occurring corrosion because of producing water as the result of reacting oxygenates with gasoline[1, 8]. Consequently, the low energy content of the fuel is obtainable[1, 8]. The most common oxygenated additives that have led to rising interest in the octane number of gasoline are Methyl Tert-Butyl ether (MTBE), alcohols such as Methanol, Ethanol, Tertiary Amyl Alcohol (TAA), and others[18].

Generally, a typical octane rating of gasoline is lower than alcohol. Therefore, adding alcohol is less operative in high-octane gasoline than in low-octane gasoline. In addition, Straight-chain alcohols have lower octane numbers than the branched chain of alcohols[1, 2,18]. (Hsieh, et al., 2002) Observed that oxygenates (Ethanol and methanol) are partial oxidizers because they have only an oxygen atom. At the same time, gasoline is composed of several hydrocarbon compounds, as mentioned in the preceding paragraph[6].

MEK and Acetones have also been accepted as chemical boosters of octane numbers[17]. Aromatic such as Aniline and BTX and branched chain hydrocarbons such as 2,2, 4-tri methyl pentanes can increase the octane number of gasoline because they are not self-igniting and aromatic contains many cyclic and the branched chain of hydrocarbons with high octane number[4, 8]. However, straight-chain hydrocarbons such as an alkane, especially octane, heptane, and Decane in gasoline, decrease their octane number because they ignite and burst readily[4, 8].

Several studies have been conducted worldwide to show the effect of oxygenated additives on the physicochemical properties and octane number of gasoline.

(Farkha, et al. 2016) Approved the impact of blending Ethanol with a sample of gasoline from the Kurdistan Region of Iraq[19]. The results of (Farkha et al. 2016) showed an improvement in RON and MON of light naphtha by blending different ratios of Ethanol with gasoline[18]. Additionally, oxygenated additives such as Ethanol and alcohols were added by (Nibal et al., 2014) into a sample of gasoline from Al-Doura Refinery in Iraq. It is shown by (Nibal et al., 2014) that adding different oxygenator ratios improved the fuel's octane number. However, the most enhancer of gasoline octane number is recorded as Aniline in their work[12]. Other oxygenated additives such as MTBE, Methanol, Tertiary butyl alcohol (TBA), and Tertiary Amyl alcohol (TAA) were added to gasoline in various proportions (Babazadeh et al., 2012) to create a new mixture of fuel. Its physicochemical properties were improved in density and volatility (distillation curves and Reid vapor pressure), and the octane number of unleaded blended gasoline was also enhanced[7]. Therefore, the effort of this study is to show the impact of oxygenated additives such as Ethanol, MTBE, and Aniline on the properties and octane number of both non-isomerized gasolines (light naphtha) from Qader Karam Refinery and ordinary gasoline from Bazian Refineries in Kurdistan Region of Iraq. Gasoline is the primary source of automotive fuel in the Kurdistan region of Iraq because most people have their cars; therefore, a considerable amount of emission gas is derived into the air daily, which is a severe problem for health conditions in that region, recently. In this research, an attempt will be applied to improve the grade of gasoline to decrease the emission of gases into the environment by improving the knock resistance of gasoline and its density and volatility.

2. Methods and Materials

2.1 Materials

First part of the materials includes two different types of base fuel: basegasoline(reformate) and sweet light naphtha. Base gasoline was obtained from the Bazian refinery in the city of Sulaymaniyah in the Kurdistan Region of Iraq, while light sweet naphtha was obtained from Qadr Karam refinery in Kurdistan-Iraq. Table 1 lists the physicochemical properties of both base fuels.

The second part of the needed material is several chemical additives that have been used to enhance the properties of both base fuels. Fuel additives were selected from different chemical groups, such as oxygenated groups, including alcohol (Ethanol) and ether (Methyl Tertiary Butyl Ether (MTEB)) and aromatic groups, such as Aniline. All chemical additives were obtained from SIGMA COMPANY, and their properties are shown in Table 2.

Table 1: Properties of the base fuels.

Properties	Quantity/gasoline	Quantity/naphtha	ASTM Method
Density /(g·cm^3) (at 16 ˚C)	0.741	0.6984	D 4052
Low heat value /(kJ·kg^{-1})	4331.3	4331.3	D 4809
Reid vapor pressure/ kPa (at 37.8 ˚C)	55.8	80.0	D 323
Sulphur/wt %	0.0509	0.0509	D 4294
Motor octane number	83.8	82.3	D 2700
Research octane number	91.5	84.9	D 2699
Antiknock index	87.6	83.6	-
Oxygen in fuel/(g·cm^{-3})	0	0	-
Distillation temperature/°C			D 86
Initial boiling point/°C	32.2	37.2	
10% Evaporated/°C	50.5	48.1	

50% Evaporated/°C	99	80.8	
90% Evaporated/°C	155.3	131.9	
Final boiling point/°C	192.3	180.3	

Table 2: The Properties of chemical additives[7-9].

Property	MTBE	Ethanol	Aniline
Chemical formula	$C_5H_{12}O$	C_2H_5OH	$C_6H_5NH_2$
Purity/%	99	99.2	99.95
Oxygen/wt%	18.2	34.7	0
Molecular weight/ (g·mol^{-1})	88.15	47.07	93.13
Density/(g·cm^3) (at 16 ˚C)	0.745	0.794	1.022
Flash point/°C	–25.6	16.6	76
Boiling temperature/°C	55	78.38	184
Ignition temperature/°C	460	363	630
Reid vapor pressure / kPa (at 37.8°C)	53.8	31.7	0.5
Motor octane number	100	100	290
Research octane number	110	115	310

2.2 Methods

All properties of mixtures were analyzed by a particular instrument called ERASPEC spectroscopy as shown in figure 1, all practical work was done in the Nation Oil Company laboratory in the city of Sulaymaniyah in the Kurdistan Region of Iraq. The analysis method is carried out in the following steps:

At the beginning of the procedure, samples are marked with the required ID and name. after that choosing the standard of measurement and the library that will be used to calculate the characteristics. Then samples should be placed next to the fuel analyzer, and insertion of the inlet tube should be placed into the sample container. Final actions followed by pressing the RUN button to start the test and receiving reading data after printing out recorded data.

Figure 1: ERASPEC spectral Fuel Analysis.

Steps for blending different chemical additives with unleaded gasoline and light naphtha bases are listed below. ASTM standard methods analyzed the physicochemical properties of the mixtures.

Stage 1- Light Naphtha as a base:

- Ethanol was added into Light naphtha with various blended rates of (5%, 10%, 15%, and 20%).
- MTEB was added into Light naphtha with various blended rates of (5%, 10%, 15%, and 20%).
- Aniline was added into Light naphtha with various blended rates of (1%, 3%, and 5%).

Stage 2- Gasoline as a base:

- Ethanol was added into Gasoline with various blended rates of (5%, 10%, 15%, and 20%).
- MTEB was added into Gasoline with various blended rates of (5%, 10%, 15%, and 20%).

Aniline was added into Gasoline with various blended rates of (1%, 3%, and 5%).

3. Results and Discussions

To choose the best type and dose of additives that improve the properties of the fuel, in this study, two groups of organic additives, oxygenates and aromatics, were used and tested on two different types of fuels: reformate gasoline and light naphthe. Fuel additives will increase combustion efficiency and reduce carbon dioxide emissions when added to fuels. Chemical additives were used in the following stages:

First stage: Oxygenate additives

In this work, oxygenates additives such as ethanol and methyl tertiary butyl ether (MTBE) were added to reformate gasoline and light naphtha at varying mixing rates of 5%, 10%, 15%, and 20% to enhance the octane rating and other properties of unleaded fuels.The oxygen content increases graduallywith the increase in the volume of oxygenate in the mixture, as shown in Figures 2 and 3. A high level of oxygen in the fuel leads to the complete combustion of the fuel in the combustion engine, thereby reducing emissions. The following properties of all blends were tested.

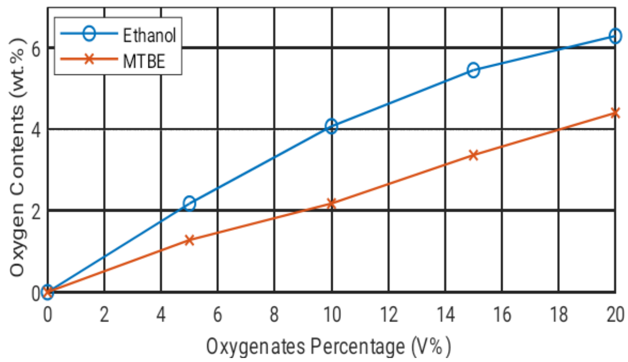

Figure 2: Volume percentage of oxygenates in light naphtha with corresponding oxygen contents.

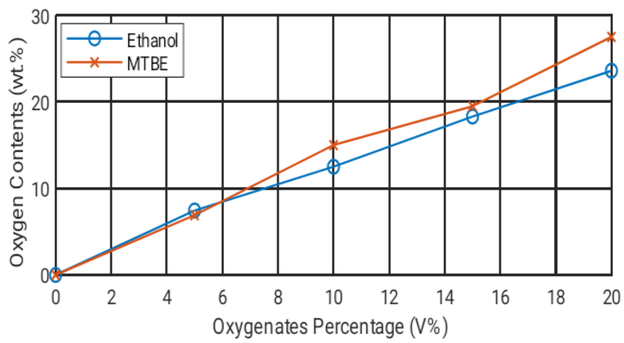

Figure 3: Volume percentage of oxygenates in gasoline with corresponding oxygen contents.

A- Octane Number

Engine knock resistance, measured by the octane value of fuel and the octane number, was evaluated using two tests based on performance; Motor octane number (MON) and Research octane number (RON). The selected oxygenate additives, Ethanol and MTBE, were added to both fuels in different proportions, then the research and motor octane numbers of all blends were measured. Figures 4, 5, 6, and 7 show the RON and MON profiles of base gasoline and light naphtha mixed with oxygenated compounds and their respective volumetric percentages. All blends' research and motor octane values show a continuous increase with increasing oxygenates volume percentages in mixtures. The results indicate that Ethanol is the most effective in increasing RON and MON gains than MTBE for both fuels because Ethanol's oxygen content is higher than MTBE's. Increasing oxygenates percentages from 15% to 20% did not show any changes in RON for gasoline. Therefore, ethanol can be considered the best octane booster for light naphtha and base gasoline in the range of (1-15% v/v). The concentration and ability of additives to change the hydrocarbon chains into cyclic or branch forms are thought to be the reasons for the high levels of octane number.

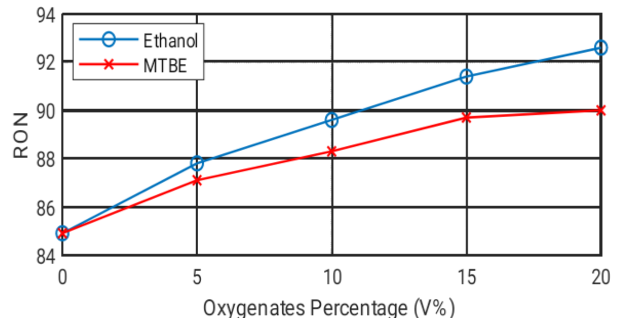

Figure 4: Research octane number (RON) of basic light naphtha with the addition of 5, 10, 15 and 20% by volume ethanol and MTBE.

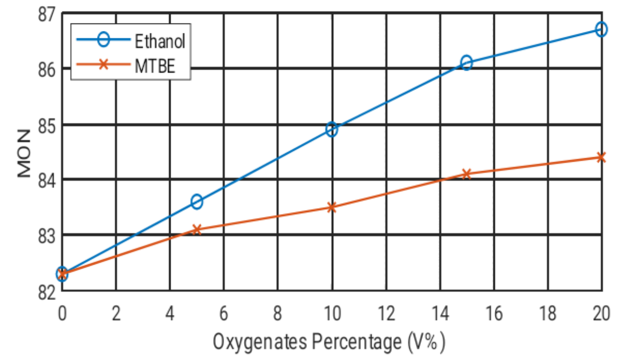

Figure 5: Motor octane number (MON) of basic light naphtha with the addition of 5, 10, 15 and 20% by volume ethanol and MTBE.

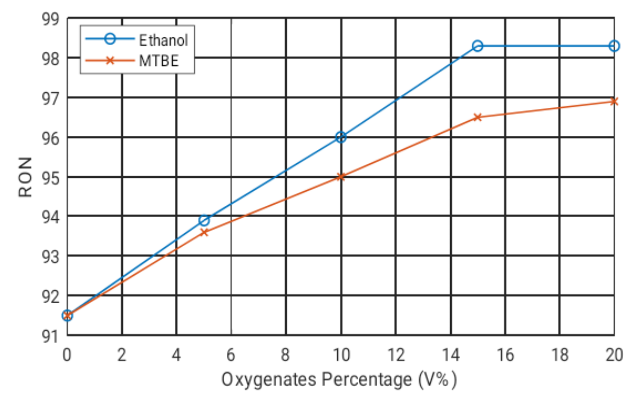

Figure 6: Research octane number (RON) of base gasoline with the addition of 5, 10, 15 and 20% by volume of ethanol and MTBE.

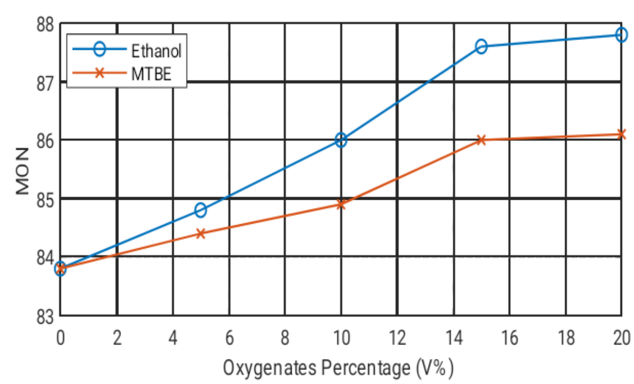

Figure 7: Motor octane number (MON) of base gasoline with the addition of 5, 10, 15 and 20% by volume ethanol and MTBE.

B- Density

Figures 8 and 9, respectively, show the densities of light naphtha and gasoline mixed with oxygenate additives in different volumetric percentages. It can be seen from these figures, the density of blends (5, 10, 15 v%) increases with the increase in the volumetric percentage of the oxygenates due to their high density compared to base fuel, Whereas, when the oxygenates percentage increased from 15% to 20 %, the blends density did not changed due to the loss of light hydrocarbons during sample preparation and analysis. Also, the probable loss of light hydrocarbons was the highest in the case of 20% MTBE[20]. Another reason for having no density change in the case of 20% MTBEis due to the molecular interactions between the additives and the base fuel[20]. Furthermore, the density increasing rate for Ethanol is more significant than for MTBE due to its high density compared to MTBE density. The amount of fuel pumped into the combustion chamber during each cycle is affected by density changes, which changes the optimal ratio of fuel-air combustion.When the fuel is mixed with denser additives, the combustion will be incomplete, which leads to the emission of pollutants into the atmosphere.

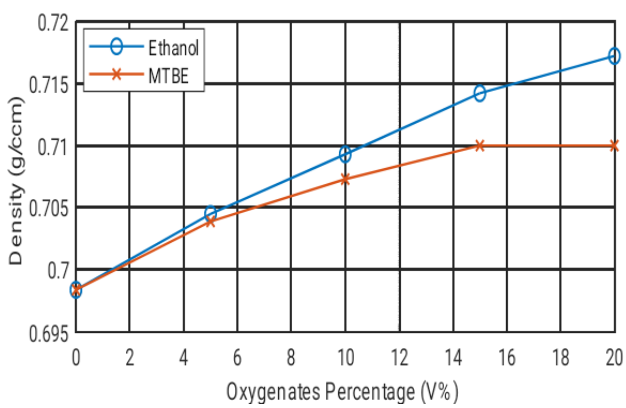

Figure 8: Light Naphtha blends densities with Oxygenated additives at (5, 10, 15, and 20% (v/v)).

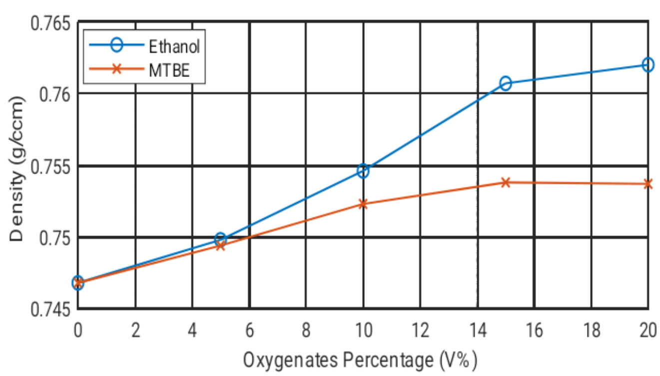

Figure 9: Gasoline blends densities with Oxygenate additives at (5, 10, 15, and 20% (v/v)).

C- Distillation Curves

Figures 10 and 11 display the distillation curves for light naphtha and its mixtures with Ethanol and MTBE, respectively, at volumes of 5, 10, 15 and 20 %, while figures 12 and 13 illustrate the distillation curves for base gasoline and its mixtures with Ethanol and MTBE at different volumes (5, 10, 15 and 20%). As shown in figures (10, 11, 12, and 13), the distillation curves of both fuels are affected by the addition of oxygenates, and this effect starts from the distillation volume from 10% to 90%. The middle part of the distillation curve, with a distillation volume of 50%, is the region most affected by the addition of oxygenates. Significantly lower distillation temperatures and more volatile fuels are achieved with increased proportions of Ethanol and MTBE due to the low boiling temperature of the oxygenates and formation of the azeotrope. Low distillation temperatures make fuel starting easier.

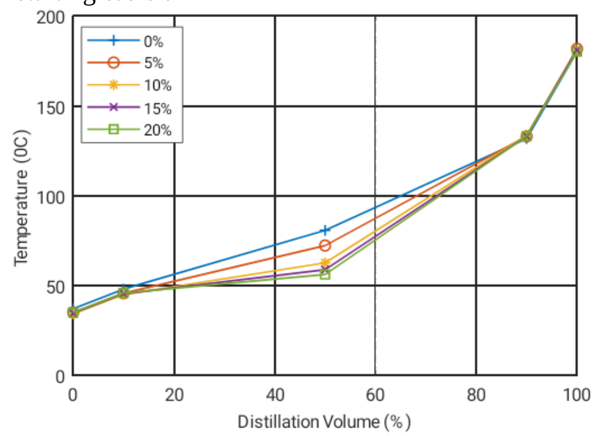

Figure 10: Distillation curves of light naphtha and its blends with ethanol in volume proportions of 5, 10, 15 and 20%.

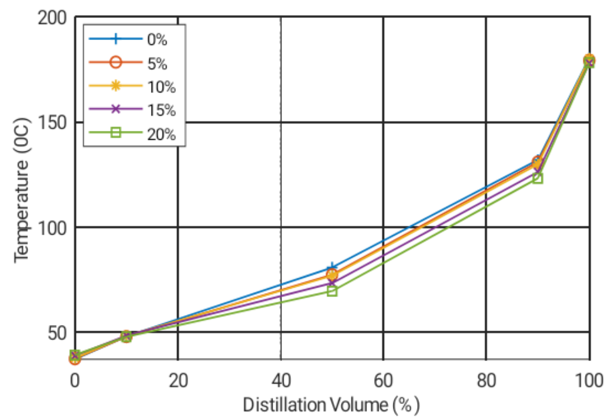

Figure 11: Distillation curves of light naphtha and its blends with MTBE in volume proportions of 5, 10, 15 and 20%.

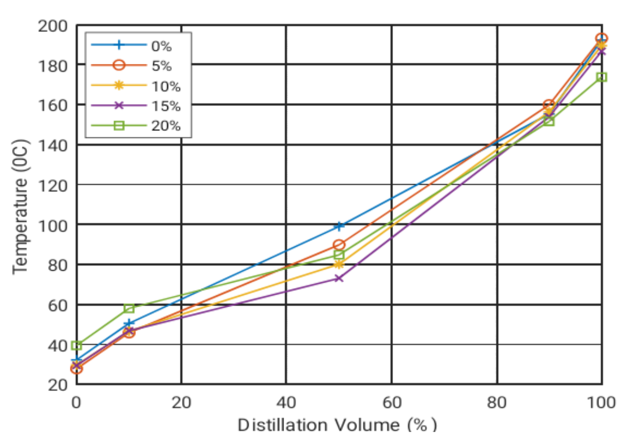

Figure 12: Base gasoline distillation curves and its blends with ethanol.

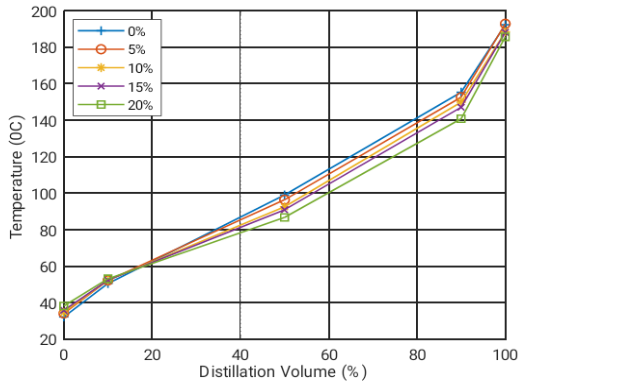

Figure 13: base gasoline distillation curves and its blends with MTBE at 5, 10, 15 and 20% v/v.

Second Stage: Aromatic additive

In another part of this study, Aniline as an aromatic additive is added to selected fuels as an antiknock agent to enhance the octane rating and other properties of unleaded fuels. Aniline was added to light naphtha and gasoline in small proportions (1%, 3%, and 5%) due to its high density, sensitivity, and molecular weight. The following properties of all blends are tested and analyzed.

A- Octane Number

Different volume proportions of the chosen aromatic component, Aniline, were added to both fuels, and the research octane numbers and motor octane numbers were measured for all blends. Mixtures are prepared in volume proportions of Aniline (1%, 3%, and 5%). From the results in figures 14 and 15, we note that adding the aromatic component had the same effect in increasing the octane values of gasoline and light naphtha blends. As it was observed when adding 1% aromatic substance, we slightly increased the octane number for both fuels. However, when adding the aromatic substance (3% and 5%) to both types of fuel, we got a high rate of increase in the octane values of gasoline, while we got a lower rate of increase in the case of light naphtha. The concentration and ability of Aniline to change the fuel chains into branch forms are thought to be the causes of high-octane number levels. From the results, Aniline as an aromatic additive is the best octane booster for light naphtha and gasoline. In addition, Aniline provides more significant octane gains than other oxygenate additives due to its high sensitivity to gasoline combustion. For example, the octane number for gasoline and light naphtha can be increased by 13 and 8 points, respectively, at an aniline concentration of 3% by volume. In contrast, an increase in octane number can be as high as 21 at 5%.

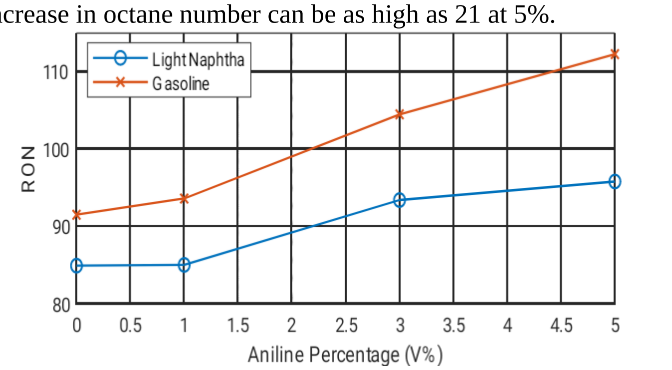

Figure 14: Research octane number (RON) for both light naphtha and base gasoline with the addition of 1, 3 and 5% by volume aniline.

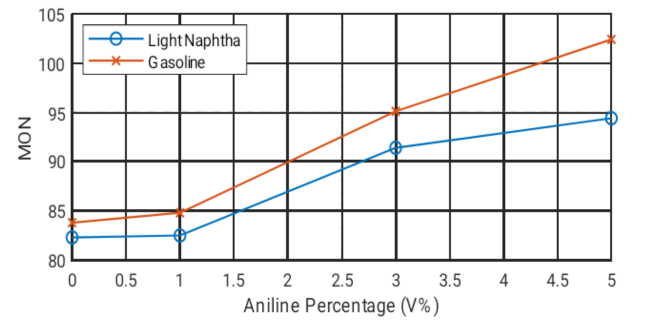

Figure 15: Motor octane number (MON) for both light naphtha and base gasoline with the addition of 1, 3 and 5%

B- Density

The densities of light naphtha and gasoline mixed with aromatic additives in different volumetric percentages (1%, 3%, and 5%) are d shown in figure 16. This graphic shows how a higher density of Aniline leads to a higher density for all blends as the concentration of aniline increases. Changes in fuel density change the amount of fuel that is forced into the combustion chamber during each cycle, which changes the ideal combustion ratio of fuel to air.

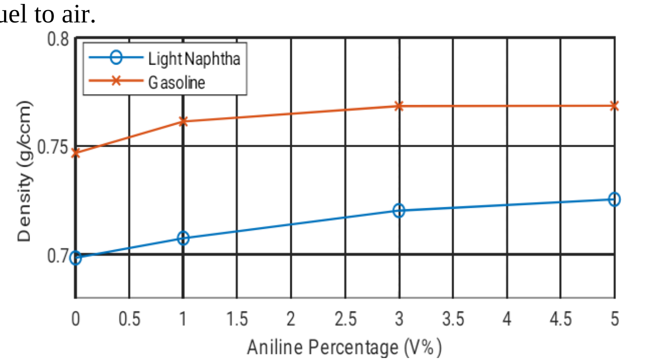

Figure 16: Density of both fuels and their blends with Oxygenate additives at (1,3 and 5% (v/v)).

C- Distillation curves

Figures 17 and 18 show the distillation curves for light naphtha and gasoline and its blends with Aniline at volumes of (0, 1, 3, and 5%) respectively. The distillation curves of light naphtha are not affected much by the addition of Aniline to it. However, adding Aniline to base gasoline increases the distillation temperature of all mixtures. It decreases their volatility due to the low difference between the boiling points of Aniline and gasoline, as well as the excellent sensitivity of Aniline in gasoline combustion. It will provide a higher RON gain.

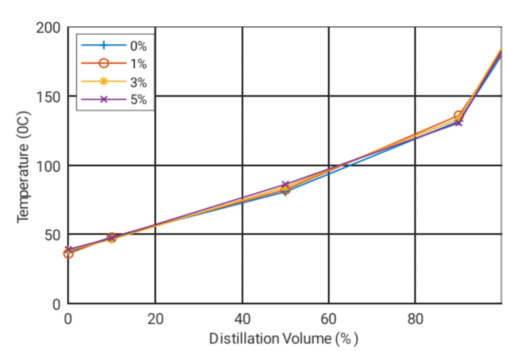

Figure 17: Distillation curves of light naphtha and its blends with aniline in the volume proportions of (1, 3 and 5% v/v).

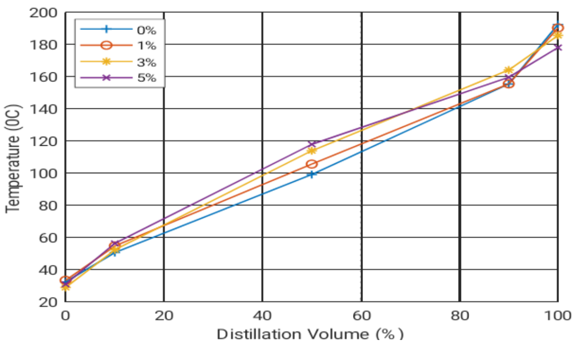

Figure 18: Distillation curves of base gasoline and its blends with aniline in the volume proportions of (1, 3 and 5% v/v).

Conclusion

This work was carried out by blending automotive fuels with selected chemical additives in order to enhance fuel properties and reduce gas emissions that are produced from the combustion of fuels. The results of blending oxegenates and aromatic additives with the fuels have shown that all additives improve the octane rating of fuels and other properties such asdensity and distillation characteristics.

In this study, Aniline has been chosen as the best octane boosterand recorded the highest RON and MON for both base fuels. The octane number of gasoline and light naphtha can be increased by 13 and 8 points, respectively, by adding only 3% of Aniline. In Addition, the blending of oxygenates to both fuels increases RON and MON.However, the results of Ethanol are more significant in the improvement of RON and MON, but adding MTBE leads to less improvement in RON and MON.

Furthermore, from the results we can conclude that the density of all mixtures increased with increasing additives volume percentage due to their higher density. Also, the distillation curves for the mixtures are also affected by the addition of oxygenates and aromatic additives, especially in the central part of the curve at a distillation volume of 50%, where distillation temperatures drop significantly with the addition of chemical additives. Moreover, having a low degree of distillation temperatures can cause the fuel to ignite quickly and easily.

Conflict of interests

None

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