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Effects of gasoline–ethanol blends on vehicle emissions and performance

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ABSTRACT

Six gasoline blends were formulated using reformate, isomerate and light naphtha, the main gasoline refinery streams produced in Egypt. Ethanol was blended in the formulated hydrocarbon gasolines at levels of 0.0, 3.0, 5.7, 7.7 and 10.0 volume percent, which meet 0.0, 1.11, 2.14, 2.87 and 3.70 percent-by-weight oxygen, respectively. Thus, seven elthanol-gasoline blends were also formulated using ethanol as an oxygenating additive and octane enhancer. The effects of ethanol addition on Reid vapour pressure (RVP), antiknock quality and tailpipe exhaust emission of the oxygenated and non-oxygenated gasoline blends, were investigated. The employed test-vehicle was a Sahin Car type 1.4S, Model 2001;4 cylinders and 1400 C.C. engine capacity. The test-vehicle was prepared in strict accordance and emission tests were conducted using a portable Sun Gas Analyzer MGA 1200. Idle speed, 660-690 rpm, was measured using fluke800. The obtained results reveal that adding ethanol to hydrocarbon gasoline, in amounts ranging from 3.0 to 10.0% by volume, increases the RVP of the resulting blends by as much as 1psi. The results also show that the impact of ethanol on RVP and octane number varied depending on the blend's composition and ethanol content. Adding 10 volume percent ethanol increases RVP of reformate, isomerate and light naphtha by 1.52, 1.12 and 1.22psi, also increases the octane number by 2.0, 3.4 and 3.9, respectively. Concerning tailpipe exhaust emissions, the obtained results showed that the addition of 5.7% by volume ethanol reduces tailpipe exhaust emissions of carbon monoxide (CO) and hydrocarbons (HC). The effect on exhaust emissions of nitrogen oxides (NOx) is more variable, but at this ethanol concentration which meets 2.1% by weight oxygen, NOx emission has shown generally to decrease.

Key words: Gasoline-ethanol blends, oxygenated gasolines, Oxy-fuels, tailpipe emissions.

INTRODUCTION

Egypt plans to improve air quality by increasing the number of natural gas vehicles (NGVs) and phasing out the use of leaded gasoline. Oxygenated gasoline containing about 10 volume percent methyl tertiary butyl ether (MTBE) as octane enhancer is used to replace tetraethyl lead (TEL) and to stop lead emissions and improve air quality. With the extensive use of gasoline-MTBE blend in Egypt and other countries, MTBE has been detected in some domestic water wells in California, USA 1998. In response to concerns about this environmental disaster, a panel of different experts was formed in 1999 by the Environmental Protection Agency (EPA).[1-5] The panel recommended phasing out of MTBE based on the available data which indicate that gasoline-MTBE, blend, releases from leaking underground storage tank systems, can adversely affect the quality of drinking water. These data refer also to the detection of MTBE in water as a result of boating activities. The panel recommended accelerating studies concerning compounds that can be used as replacements.[6-8] Although ethanol, iso-octane and alkylate have frequently been discussed as attractive gasoline blend components to deal with supply issues if MTBE is eliminated, ethanol is widely considered to be the primary replacement option in several countries.[9-12] .In Egypt, MTBE was mainly used in gasoline as a high-octane blending component to replace the octane lost when lead was removed. In EPRI, oxygenated gasoline research program[13,14] begins with an overview of gasoline properties that affect emissions and engine performance and discusses how MTBE, ethanol, and other gasoline components affect those properties[13-16], which set the stage for why ethanol is one of the likely substitutes for MTBE. The present paper is a continuation for this trend.

EXPERIMENTAL SECTION

2.Experimental setup and procedure

2.1.Refinery Streams and Ethanol

Reformate, isomerate and light naphtha were kindly supplied by Cairo Petroleum Company, Mostorod Refinery Table [1] lists GC individual analysis and some of these distillates as received from the producer. Absolute ethyl alcohol ~ 99% was purchased from Adwic for gasoline-ethanol formulations.

2.2.Gasoline Formulations

Six hydrocarbon gasoline blends, designated G-RS-1, G-RS-2, G-RS-3, G-RS-4 G-RS-5 and G-RS-6 were prepared volumetrically using combinations of the neat refinery streams (reformate, isomerate and light naphtha) without any added alcohol. These non-oxygenated blends were used as reference samples for the sake of comparison with the oxy-fuels. Other seven gasoline-ethanol blends were formulated using the same refinery streams and 3.0, 5.7, 7.7 and 10.0 volume percent ethanol. Ethanol-gasoline blends, designated G-3.0-E, G-5.7-E, G-7.7-E and G-10-E are clear solution without any detectable phase separation. All the formulated test fuel blends, ten-litre each, were kept refrigerated (below 5^{o}C) in well-stoppered labelled containers. An ice-box was used to keep these blends refrigerated when sent for octane number test and tailpipe emission analysis.

2.3.Test Vehicle

The test vehicle was a Sahin car type 1.4s, Model 2001, manufactured by El-Nasr Automotive Manufacturing Co., Wadi Hoff, Helwan, Cairo, Egypt. The test vehicle has the following technical data:-Engine: 131^{FI} 0.16, No 6628968-4 cylinders (in line) Engine Capacity: 1400 c.c., Engine location: front, Bore: 80.5 mm, Stroke: 67.4 mm, Compression Ratio: 8.3:1, Max. Power output: 78HP at 5500 rpm, Max. Torque: 10.7 kg. m at 3000 rpm, Idle speed: 900 ± 50 rpm, Max. speed: 145 km/h.

2.4. Vehicle/ Engine Preparation and Emission Test

The test vehicle was prepared in strict accordance with the reported requirements[17,18].

RESULTS AND DISCUSSION

3.1. Gasoline and Gasoline-Ethanol Blend Formulation

In this study, three refinery streams, namely, reformate, isomerate and light naphtha, were employed in all the formulated fuel blends. Table [l] lists individual gas chromalographic analysis of these hydrocarbon gasoline components. Six reference hydrocarbon gasoline blends were formulated volumetrically from these components. These blends were designated G-RS-1,G-RS-2, G-RS-3,G-RS-4,G-RS-5 and G-RS-6. Composition, Reid vapour pressure (RVP),aromatic content and octane number of these non-oxygenated blends are presented in Table [2]. In this study, non-oxygenated blends were used as reference gasoline (G-RS) blend for the sake of comparison with the investigated oxy-fuels.

Other seven gasoline-ethanol blends were formulated using the same refinery streams and 3.0, 5.7, 7.7 and 10.0 volume percent ethanol. Gasoline-ethanol blends, designated G-3.0-E, G-5.7-E, G-7.7-E and G-10-E, are clear solutions without any detectable phase separation. Designations along with some key properties of the formulated ethanol-gasoline blends are presented in Table [3]. In these designations, letter E_1 denotes ethanol and number 1 refers to the non-ethanol gasoline from which an ethanol gasoline blend was reformulated. For instance, ethanol-gasoline blends designated G-3.0-E_1, G-5.7-E_1, G-7.7-E_1, and G-10-E_1, in Table [3], are all reformulated from the non-ethanol (i.e., non-oxygenated or hydrocarbon reference) G-RS-1 gasoline (Table 2) after blending with 3.0, 5.7, 7.7 and 10.0 volume percent ethanol.

3.2. Gasoline and Oxygenating Additives

Oxygenates are oxygen-rich substances that should dissolve well in gasoline and make it burn better, thus reducing carbon monoxide and other emissions [19]. MTBE is the fuel oxygenate preferred by oil companies, because it is cheaper to make from the refinery waste-streams, has about the same heating value as gasoline, mixes well with gasoline, and does not increase the gasoline vapour pressure. MTBE has a terrible taste and adour, and can easily foul up water in drinking wells[19].

Use of ethanol as a gasoline additive has other environmental impacts. Most gasoline is stored in underground tanks, which sometimes leak[20]. If a leak occurs, ethanol and gasoline contaminate soil and dissolve into ground water. Soil bacteria will metabolize ethanol first and the subsurface plumes of gasoline spread farther, and can poison more water wells. [21,22]However, the real problem with ethanol has been explained through several studies[20,23,24] concerning efficiency of biomass conversion to ethanol and the overall energy balance of ethanol produced from corn starch, wood cellulose and wood hemicellulose.

Table 1 GC Analysis and Properties of Refinary Streams Used for Gasoline Formulations

Composition,ωt %	Reformate 21 C_1 Bott.	Isomerate 30 – SN - 5	L.Naphtha Top C_7
Iso – Butane	1.01	0.40	0.00
n – Butane	0.43	3.75	0.00
iso – Pentane	1.60	36.1	12.00
n – Pentane	1.65	10.22	17.03
2,2 – Dimethylbutane	0.30	11.42	0.25
Cyclopentane	0.10	1.47	1.70
2,3 – Dimethyl butane	0.30	3.85	1.13
2 – Methyl Pentane	3.01	12.11	7.21
3 – Methyl Pentane	1.70	7.33	6.04
n – Hexane	2.35	5.15	13.01
Methylcyclopentane	0.72	3.43	5.65
Benzene	3.51	0.03	3.30
Cyclohexane	0.14	3.14	5.26
C_7^+	83.18	1.60	27.42
Total	100.00	100.00	100.00
Sp. Gravity 60/60 °F	0.6831	0.5441	0.6571
Sulphur ,ωt % (ppm)	0.1022 (102)	0.0563 (56)	0.1080 (108)
RON	93.7	86.0	69.0
MON	83.6	84.1	68.8
(R+M)/2	88.6	85.0	68.9

Table 2 Designation and Composition of Six Formulated Non-Oxygenated Gasoline Blends

Designation	Composition, vol%		RVP, psi	Aromatics vol%	O.N (R+M)/2
G-RS-1	Reformate Isomerate L.Naphtha	72 22 6	6.28	43.0	87.3
G-RS-2	Reformate Isomerate L.Naphtha	62 22 16	7.04	37.0	83.4
G-RS-3	Reformate Isomerate L.Naphtha	56 34 10	7.32	32	83.7
G-RS-4	Reformate Isomerate L.Naphtha	68 22 10	6.98	39.0	84.3
G-RS-5	Reformate Isomerate L.Naphtha	72 18 10	6.18	41.0	86.0
G-RS-6	Reformate Isomerate L.Naphtha	76 14 10	6.12	43.0	87.2

3.3. Effect of Added Ethanol on RVP

Two hydrocarbon test fuels, designated G-RS-1 and G-RS-2 were employed to study the effect of added ethanol on the Reid vapour pressure (RVP) and octane numbers (O.N) of these fuels. G-RS-1 was formulated volumetrically from 72% reformate, 22% isomerate and 6% light naphtha. G-RS-2 consists of 62% reformate, 22% isomerate and 16% light naphtha. Ethanol exhibits a high vapour pressure when blended with the hydrocarbons of gasoline[7,25]. The RVP impact of the ethanol addition is quite non-linear as shown in Figure[1]. The addition of 7.7 percent ethanol to a base 7 RVP gasoline raises the RVP by slightly over 1 psi, while the addition of 10 percent ethanol increases theRVP a little less than 1 psi. It is noteworthy that 10 percent ethanol addition to a base 7 RVP and 6.28 RVP gasoline resulted in approximately the same net RVP increase (i.e, 1.14 and 1.28 psi). The oxygen content is an important factor in making oxygenated gasolines. Currently, a minimum of 2 percent by weight oxygen is required [7]. MTBE and ethanol are the two primary oxygenates used in reformulated gasoline. MTBE has half as much oxygen content by weight as does ethanol, so twice as much volume of MTBE is needed to meet the 2-percent-by-weight requirement. Generally, this translates to about 11.2 percent by volume of MTBE and 5.7 percent by volume ethanol. In the present study, 3.0, 5.7, 7.7 and 10.0 volume percent ethanol were employed which meet 1.11, 2.14, 2.87 and 3.70 percent-by-weight oxygen. The oxygenated test fuels, which were employed in tailpipe emission analysis, are all gasoline-ethanol-blends containing 5.7 volume percent (~ 2.1 weight percent oxygen). Many refiners will only use 5.7 percent ethanol in their reformulated gasolines, rather than higher amounts both for economical and emission constrain reasons[26]. It has been concluded that when ethanol is added to gasoline, the RVP increases and thus volatile organic compounds (VOC) emissions increase. To counter the increase, the remaining base gasoline must be adjusted to a lower RVP. For the summer blends, the RVP of gasoline feed stocks for ethanol blending must be reduced by about 1.0 to 1.3psi. This reduction in RVP is accomplished by removing "light ends" to keep RVP down, and removing "heavy ends" to reduce T_{50} and T_{90} distillation temperature [7]. The effect of added ethanol on RVP of each of the employed refinery streams was studied. The obtained results are illustrated in Figure[2]. As can be seen from this figure, up to 10 percent ethanol the relationship approached linearity and a net increase of 1.52,1.12 and 1.22 psi in the RVP of reformate, isomerate and light naphtha , respectively. Blends exceeding 10 volume percent ethanol are not permitted by law, nor are they likely to occur, because ethanol costs much more than gasoline, making higher-level blends uneconomical

Table 3 Designations and Composition of Seven Formulated Oxygenated Gasoline Blends

Designation	Composition, vol%		RVP, psi	Aromatics vol%	O.N (R+M)/2
G-3.0-E_1	Reformate Isomerate L.Naphtha Ethanol	69.8 21.4 5.8 3.0	6.60	42.0	87.8
G-5.7-E_1	Reformate Isomerate L.Naphtha Ethanol	67.9 20.7 5.7 5.7	7.02	41.0	87.9
G-7.7-E_1	Reformate Isomerate L.Naphtha Ethanol	66.5 20.3 5.5 7.7	6.97	40.0	88.0
G-10-E_1	Reformate Isomerate L.Naphtha Ethanol	64.8 19.8 5.4 10.0	7.56	39.0	88.3
G-5.7-E_4	Reformate Isomerate L.Naphtha Ethanol	64.1 20.8 9.4 5.7	7.41	35.0	84.9
G-5.7-E_5	Reformate Isomerate L.Naphtha Ethanol	67.9 17.0 9.4 5.7	6.82	37.0	86.7
G-5.7-E_6	Reformate Isomerate L.Naphtha Ethanol	71.7 13.2 9.4 5.7	6.73	40.0	87.8

Table 4 Effect of Added Ethanol on Volatility Criteria, Driveability Index and Octane Number of Gasoline G-RS-1

Specifications	G-RS-1	G -3.0E_1	G -5.7E_1	G -7.7E_1	G -10E_1
Composition, vol.%					
Reformate	72.0	69.8	67.9	66.5	64.8
Isomerate	22.0	21.4	20.7	20.3	19.8
Light Naphtha	6.0	5.8	5.7	5.5	5.4
Ethanol	0.0	3.0	5.7	7.7	10.0
Octane Number*					
Ron	90.5	90.4	91.2	93.1	93.2
Mon	84.0	85.5	86.0	85.8	85.9
(R+M)/2	87.3	87.9	88.6	89.4	89.6
Volatility Criteric*					
E70, Vol%	30	28	25	23	18
E100,Vol%	60	58	54	48	44
E150,vol%	87	85	84	82	80
Driveability Index					
DJ (^oF)	1330	1273	1202	1125	1078
DI (^oC)	641	609	570	527	498

** From distillation profiles through computational approach.*

Table 5 Effect of Ethanol on Volatility Criteria, Driveability Index and Octane Number Of Gasoline G-RS-3

Specifications				
	G-RS-3	G -5.7E_3	G -7.7E_1	G -10E_3
Composition, vol.%				
Reformate	56.0	52.8	51.7	50.4
Isomerate	34.0	32.1	31.4	30.6
Light Naphtha	10.0	0.4	9.2	9.0
Ethanol	0.0	5.7	7.7	10.0
Octane Number*				
Ron	86.9	86.8	87.1	87.3
Mon	80.5	81.5	81.9	82.3
(R+M)/2	83.7	84.1	84.5	84.8
Volatility Criteric*				
E70, Vol%	35	30	26	21
E100,Vol%	62	55	50	45
E150,vol%	89	87	83	80
Driveability Index				
DJ (^{o}F)	1206	1222	1147	1054
DI (^{o}C)	642	509	550	

** From distillation profiles through computational approach.*

3.4. Effect of Added Ethanol on Octane Quality of the Fuel

The addition of 10 volume percent ethanol contributed 2.3 and 2.8 antiknock indices (AKI) to the finished G-RS-1 and G-RS-2 gasoline blends (Figure3). AKI measures the ability of a gasoline to resist engine knock. AKI is the average of Research and Motor Octane or (R+M)/2. AKI is commonly referred to as pump octane. Motor Octane Number (MON) affects high speed and part throttle knock and performance under load, passing climbing hills, etc. Research Octane Number (RON) affects low to medium speed knock and engine run-on. RON is the higher of two numbers. It is obvious from (Figure 3) that the octane number of hydrocarbon gasoline G-RS-1 is higher than that of G-RS-2 blend. This is due to the difference in composition, which dictates the octane number of the final blend. In G-RS-1, reformate, the high octane component, is the larger volume ingredient, whereas, light naphtha, the low octane ingredient, is the smaller volume ingredient than in G-RS-2 blend. It can be concluded that the contribution of ethanol, as an octane enhancer oxygenate, to octane number depends mainly on the composition of hydrocarbon components of gasoline blend and the amount of added oxygenate. Refiners usually formulate gasoline blends having the required volatility and octane number by using different refinery streams of known quality, Refinery streams such as LSR (Light Straight run gasoline or light naphtha), isomerate, reformate, alkylate (C_3 and C_4 alkylate), FCC (fluid catalytic cracking) and iso-octane, are commonly used for gasoline formulations in many refineries. In Egypt, reformate, isomerate and light naphtha are the employed gasoline blend components. Addition 5.7 volume percent ethanol (~ 2.0% by weight oxygen content) resulted in an increase of 2.9, 1.1 and 0.4 in the AKI values of light naphtha, reformate and isomerate, respectively. The addition of 10 volume percent ethanol (~ 3.7% by weight oxygen content) contributed 3.9, 3.4 and 2.0 AKI to light naphtha, isomerate and reformate, respectively (Figure 4).

Table 6A Tailpipe Emission Analysis of Non-Oxygenated Gasoline Blends

Gasoline Blend Component, (vol %)	Designation		
	G-RS-4	G-RS-5	G-RS-6
Reformate	68.0	72.0	76.0
Isomerate	22.0	18.0	14.0
L.Naphtha	10	10.0	10.0
Total	100.0	100.0	100.0
Specifications			
Oxygen content	0.0	0.0	0.0
Octane(R+M)/2	84.3	86.0	87.2
RVP,psi	7.0	6.2	6.1
Benzene , ωt%	2.1	2.3	2.4
Aromatics, vol%	39.0	41.0	43.0
Sulphur , ppm	<100	<100	<100
Volatility Criteria			
T50,ASTM-D86,C$^\circ$	86	88	89
T90,ASTM-D86,C$^\circ$	150	152	153
E70, vol% Recovered	33	31	28
E100,vol%Recovered	60	59	57

Tailpipe Emission			
HC, ppm	495	503	508
CO , Vol %	4.58	4.69	4.81
NO_x , ppm	48.0	45.0	47.0

Table 6B Tailpipe Emission Analysis of Oxygenated

Gasoline Blend Component (vol %)	Designation		
	G-5.7-E_4	G-5.7-E_5	G-5.7-E_6
Reformate	64.1	67.9	71.7
Isomerate	20.8	17.0	13.2
Light Naphtha	9.4	9.4	9.4
Gasoline	94.3	94.3	94.3
Ethanol	5.7	5.7	5.7
Total	100.0	100.0	100.0
Specifications			
Oxygen content	2.1	2.1	2.1
Octane(R+M)/2	84.9	86.7	87.8
RVP, psi	7.41	6.82	6.73
Benzene , ωt%	<2.0	<2.0	<2.0
Aromatis , vol%	35.0	37.0	40.0
Sulphur , ppm	<100	<100	<100
Volatility Criteria			
T50,ASTM-D86,C°	93	95	96
T90,ASTM-D86,C°	161	163	164
E70, vol%	28	26	24
E100, vol%	54	53	51
Emission			
HC, ppm(%reduction)	402(18.7%red.)	408(18.9%red.)	398(21.7%red.)
CO , vol %(% red)	3.68(19.7%red.)	3.79(19.2%red.)	3.94(18.1%red.)
NO_x , ppm(% red)	46.0(4.2%red.)	45.0(0.0 red.)	45.0(4.3%red.)

3.5. Other Specifications of Gasoline-Ethanol Blends

The ability of ethanol to form azeotropes with gasoline hydrocarbons due to its molecular polarity means that the characteristics of the mixture into which it is blended will be significantly modified[11,27]. The principal changes in the fuel properties due to the addition of ethanol to gasoline include: increased octane number and increased volatility as discussed in the preceding part. However it is important to note that it is one of only three tests for monitoring and controlling fuel volatility. The V/L ratio and vapour pressure tests are measurements of a fuel's "front end volatility", or more volatile components, which vaporize first. The distillation test is used to determine fuel volatility across the entire boiling range of gasoline. Distillation profiles were constructed in this study for all the investigated non-oxygenated (non ethanol) and oxygenated (gasoline-ethanol) blends to study the effect of added ethanol on the distillation profile and volatility criteria of the six reference hydrocarbon gasoline blends designated G-RS-1-G-RS-6. Figures [5] and[6] are representative figures.

Figure[5] illustrates the distillation curves of G-RS-1, the reference hydrocarbon gasoline blend, and G-5.7-E_1, G-7.7-E_1, and G-10-E_1, the gasoline-ethanol blends which were reformulated from G-RS-1 by the addition of 5.7, 7.7 and 10.0 volume percent ethanol. For instance, G-5.7-E_1 gasoline blend consists of 94.3 volume percent of the hydrocarbon gasoline G-RS-1 and 5.7 volume percent ethanol. Through computational approach, polynomial equations representing the obtained distillation curves of the investigated blends, were determined (R-square values indicate the reliability of the developed equations). From these equations, points such as E70, E100 and E150 could be located accurately[28,29]. Also, the area under the curves of oxygenated and non-oxygenated blends could be easily calculated to determine the % difference in volatility [28,30]. Careful inspection of the constructed distillation curves in Figure [5] reveals that the lowest curve represent the non-ethanol G-RS-1 gasoline blend which has 6.28psi RVP. The upper curves represent gasoline-ethanol blends G-5.7-E_1, G-7.7-E_1 and G-10-E_1, which have 7.02, 6.97 and 7.17 psi vapour pressure. In each distillation curve, a set of "E" points are located . E70, E100 and E150 are the volume percentages of gasoline distilled at 70,100 and 150^{o}C. Volatility criteria, E70, E100 and E150 represent front-end, mid-range, and tail –end volatilities, respectively. Front-end volatility, E70, is adjusted to provide: easy cold and hot starting, freedom from vapour lock, low evaporative emissions. Mid-range volatility, E100, is adjusted to provide: rapid warm-up, smooth running, protection against carburetor icing and hot stalling, good power and acceleration. Tail-end volatility, E150, is adjusted, to provide: minimal hydrocarbon (HC) exhaust emission, minimal fuel dilution of crankcase oil, freedom from engine deposits and good fuel economy [31,32] In this study, E150 value is used to fix back-end volatility. To minimize derivability problems and comply with environmental standards, the European Programme on Emissions-Fuel and Engine Technologies (EPEFE), has accepted that E150 to be equal to T90% in many formulation designs[17]. All the formulated fuel blends in this study were designed to evaporate by 190°C to avoid harmful exhaust emissions of heavy gasoline components[33,34]. Table [4] lists the composition, specifications and octane numbers of the non-ethanol G-RS-1 gasoline blend along with four gasoline-ethanol blends G-3.0-E_1, G-5.7-E_1, G-7.7-E_1 and G-10-E_1 which constitute 3.0, 5.7, 7.7 and 10.0 volume percent ethanol, respectively. Octane numbers, volatility criteria and driveability indices of these blends are listed in this table. Data in Table [4] depicts the effect of added ethanol on the main properties of gasoline-ethanol blends as compared with the hydrocarbon-base gasoline G-RS-1. It can be seen from data in Table[4] that the addition of ethanol resulted in a detectable increase in the vapour pressure and antiknock index, AKI, known as pump octane (R+M)/2. The five investigated fuels in Table [4] which have 5 levels of ethanol (0.0, 3.0, 5.7, 7.7 and 10.0% by volume) gave T50% values at 89, 92, 96, 103 and 106°C, and T90% values at 151, 155, 162, 168 and 172°C respectively. This indicates that addition of ethanol to a hydrocarbon-base gasoline increases its volatility. E70 and E100, vol% values decrease with increasing ethanol content. This means that in ASTM-D86 distillation, 70°C is reached at 30 volume% recovery of G-RS-1 and at 20 volume% recovery of G-10-E_1, respectively.

Figure [6] illustrates Similarly, the effect of added ethanol on distillation profiles and volatility criteria of the reference hydrocarbon gasoline G-RS-3, and the gasoline-ethanol blends G-5.7-E_3 ,G-7.7-E_3 and G-10-E_3. From the constructed distillation profiles and the developed equations, E70, E100 and E150 values were determined for the hydrocarbon and gasoline-ethanol blends. Table [5] lists the composition, specification, octane number, volatility criteria and driveability indices

While octane and volatility are the most important standards relating to drivability[31], there are other fuel standards covered by ASTM guidelines.

3.6. Driveability Index (DI)

While each change of the distillation profile is important, gasoline represented by the entire profile is what the engine must distribute, vapourise and burn. To predict cold start and warmup driveability, DI has been developed[35] using the temperatures, in degrees Fahrenheit, for the evaporated percentages of 10% (T_{10}), 50% (T_{50}) and 90% (T_{90})-ASTM-D86 test Method.

$$DI\ (^oF) = 1.5\ (T_{10}) + 3.0\ (T_{50}) + (T_{90}) \quad \text{…. [1]}$$

The DI varies with gasoline grade and season; the normal range is 850 to 1300. Lower values of DI generally result in better cold-start and warmup performance, but once good driveability is achieved, there is no benefit to further lowering the DI (ASTM- D4814 Test Method). Excessively high T_{50} (low E100) can lead to poor starting and warm-up performance at moderate ambient temperatures.

The Co-ordinating Research Council (CRC, US) has continued to improve the DI equation and to make it universally applicable [35]. An oxygen correction factor has been introduced for gasoline-ethanol blends when compared to all-hydrocarbon gasoline blends. Equation [2] has been developed (temperatures are in degrees celcius) and the conversion formula [3] is to be used (ASTM-D4814).

$$DI\ (^oC) = 1.5\ (T_{10}) + 3.0\ (T_{50}) + (T_{90}) + (11x\ wt\%\ Oxygen) \quad \text{…. [2]}$$

$$DI\ (^oC) = (DI\ ^oF - 176) / 1.8 \quad \text{….. [3]}$$

Calculated DI values of the formulated gasoline-ethanol blends and hydrocarbon gasoline blends are listed in Tables [7B] and [8B] using equations [2] and [1]. DI values shown in these tables indicate that gasolines containing 0.0-10.0 volume percent ethanol (0.0-3.7 weight percent oxygen) have DI (°F) values within those specified above, i.e. in the range 580-1300. Some investigators have suggested a similar ether oxygenate correction. The magnitude of such correction will be determined when enough data are available [35]. Data in Table [5] show the effect of added ethanol on specification, octane number, volatility and driveability index of the reference hydrocarbon blend G-RS-3, and the corresponding gasoline – ethanol blends , G- 5.7-E3 , G-7.7-E_3 and G-10-E_3.These formulations were originally designed to have less aromatic contents (32-29 vol%) and higher vapour pressure values (7.3-8.4psi) if compared with formulations in Table [5] which have relatively higher aromatic contents (43-38 vol%) and lower vapour pressure values (6.3-7.2 psi). This was accomplished by changing the composition of the hydrocarbon base blends prior to addition of ethanol. G-RS-1 consists of 72 vol% reformate (aromatic-enriched component), 22 vol% isomerate and 6 vol% light naphtha.

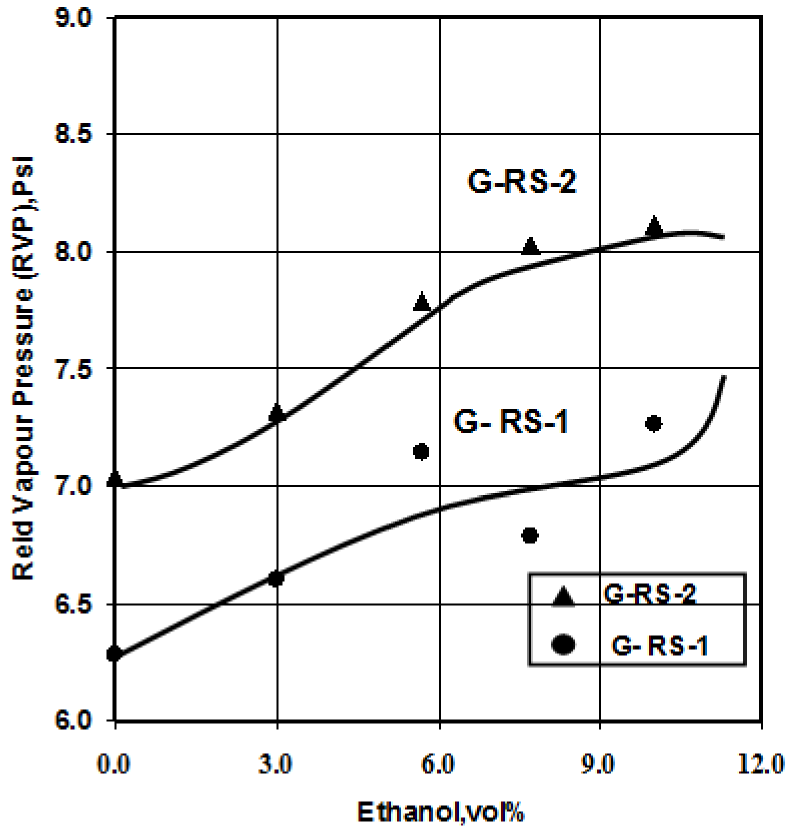

Figure 1- Effect of Added Ethanol on Reid Vapour Pressure of Two different Reference Hydrocarbon Gasoline Blends.

G-RS-3 consists of 56 vol% reformate, 34 vol% isomerate (high RVP component) and 10 vol% light naphta (Table 4). The composition of the hydrocarbon-base formulation dictates the required specifications of the final blend. For example, when 10 volume percent ethanol is blended with other hydrocarbon gasoline components to create a finished blend of about 8.4 psi vapour pressure, the final blend's vapour pressure is about 1.1 psi higher than the vapour pressure (RVP) of the non ethanol components comprising 90.0 volume percent of the final mixture (Table 5). To counter the increase in vapour pressure due to ethanol addition, the composition of the base gasoline must be adjusted to a lower RVP. For summer blends, the RVP of blend stocks for ethanol blending must be reduced by 1.3 psi [7,11]. This is accomplished by removing the "light ends" to keep RVP down. After removal of light materials (C_4 and C_5 hydrocarbons), refiners use less ethanol volume (moving from 10.0 to 5.7 volume percent). The elimination of light, high RVP components in combination with a reduction in volume of ethanol causes the T50 and T90 distillation temperatures for the gasoline-ethanol blend to rise. Refiners will then need to remove "heavy ends" to reduce T_{50} and T_{90}[5,7] Refiners have several options to make up for the loss in volumes of summer gasoline when they switch from 10.0 to 5.7 vol% ethanol. The best option will be to produce or purchase more alkylate or iso-octane [7].

3.7.Tailpipe Exhaust Emissions

In this study, three reference hydrocarbon gasoline test fuels along with three other gasoline-ethanol blends, were tested for their tailpipe exhaust emissions using the same test vehicle. Specifications and volatility criteria of the reference hydrocarbon gasoline test fuels (G-RS-4, G-RS-5 and G-RS-6)and gasoline-ethanol blends (G-5.7-E_4,G-5.7-E_5 and G-5.7-E_6) are given in Tables[6A] and [6B], respectively. Gasoline-ethanol blends were formulated from the corresponding hydrocarbon reference ones by blending 5.7 volume percent ethanol (which meets 2.1 wt% oxygen) with 94.3 volume percent hydrocarbon gasoline. Blending of ethanol oxygenate leads to alterations in blend composition. Fuel properties such as aromatic content, pump octane, (R+M)/2, vapour pressure and volatility criteria, are considered which may influence gasoline related vehicle emissions. The employed test vehicle was a Sahin Car type 1.4S Model 2001. Emission analysis were carried out using Sun Gas Analyzer MGA 1200, Idle speed (660-690 rpm) was measured using Fluke 800. It is well-known that oxygenates, such as alcohols and ethers, are mostly known for their ability to reduce CO emissions by enleaning the fuel-to-air mixture. Though enleanment generally has the most influential effect on CO emissions, the sensitivity to aromatic level gives indications that other fuel properties have additional influence. At higher oxygen content, i.e. higher than 2.0 weight percent, more lowering of CO emissions are expected but certainly will increase the HC emissions due to increase in volatility as indicated from T_{50} and E_{70} values [28-30]. Oxygenated test fuels having the same oxygen content (~ 2.0 wt%) but different aromatic levels, were tested for their HC, CO and NOx emissions. Non-oxygenated gasoline blends were used as reference fuels. The study reveals that the addition of 5.7 volume percent ethanol reduces exhaust emissions of carbon monoxide (CO). The achieved exhaust CO reductions have reached 19.7, 19.2 and 18.1%, whereas the obtained HC reductions are 18.7, 18.9 and 21.7% for G-5.7-E_4, G-5.7E_5 and G-5.7-E_6, respectively. Blending of 5.7 volume percent ethanol oxygenate in gasoline minimizes the amount of complete combustion and hence the amount of CO produced. Blending of this amount of ethanol leads to alterations in blend composition, subsequently, aromatic contents are reduced from 39-43 to 35-40 (Tables 6A and 6B). Reduction in aromatic levels will also contribute to lower CO emissions [28,29] The effect of oxygenates on NOx emissions is less certain; theoretically, adding oxygenate could lead to higher NOx emissions relative to non-oxygenated blends, especially at higher oxygenate concentrations [28]. In the present study, emission results cannot accurately characterise the percent reduction that could result between non-oxygenated and oxygenated blends as shown in Tables[6A] and [6B]. It could be concluded that insignificant difference could be detected between NOx emissions of oxygenated and non-oxygenated blends. More emission tests have to be carried out using oxy-fuels of different composition; volatilities and different aromatic contents. However at this ethanol concentration, which meets 2.1% by weight oxygen, NOx emission has shown generally to decrease[36].

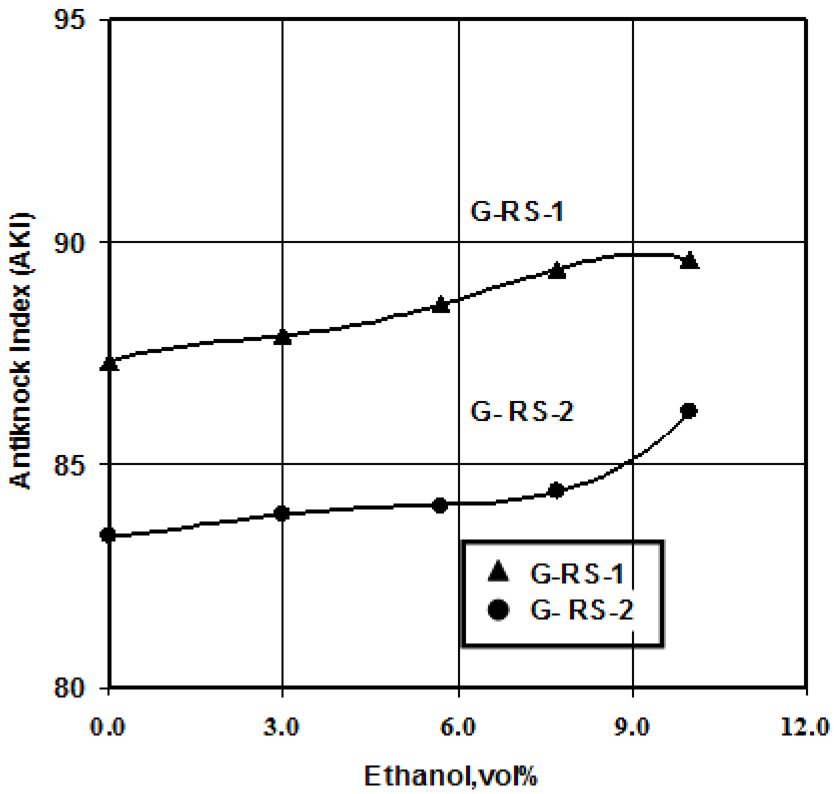

Figure 2- Effect of Added Ethanol on Antiknock, Index (AKI) of Two Different Reference Hydrocarbon Gasoline Blends.

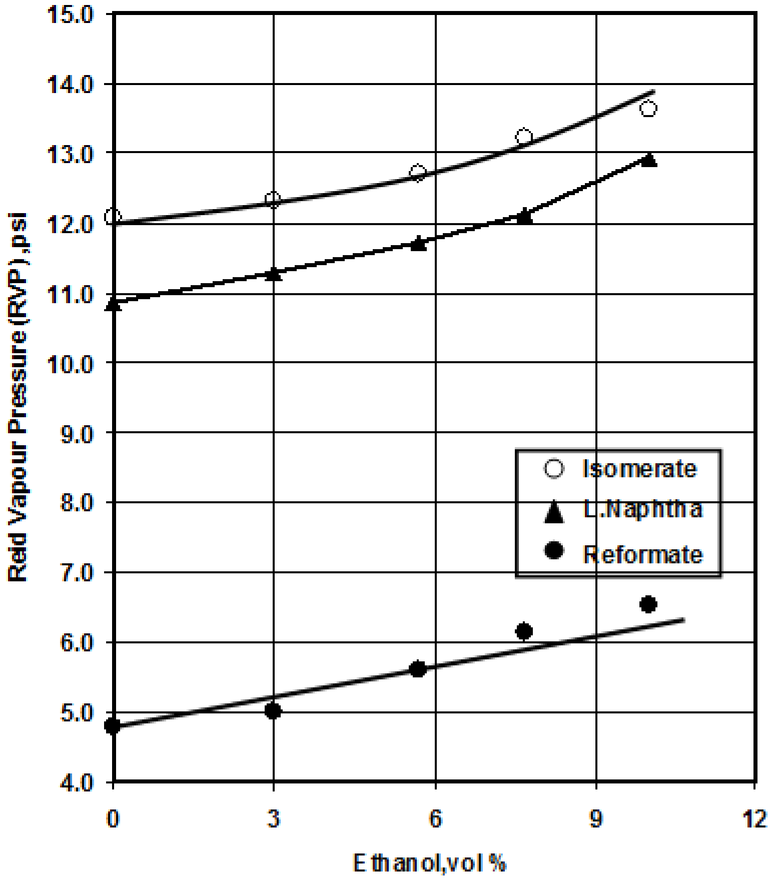

Figure 3- Effect of Added Ethanol on RVP of Three Gasoline Refinery Streams.

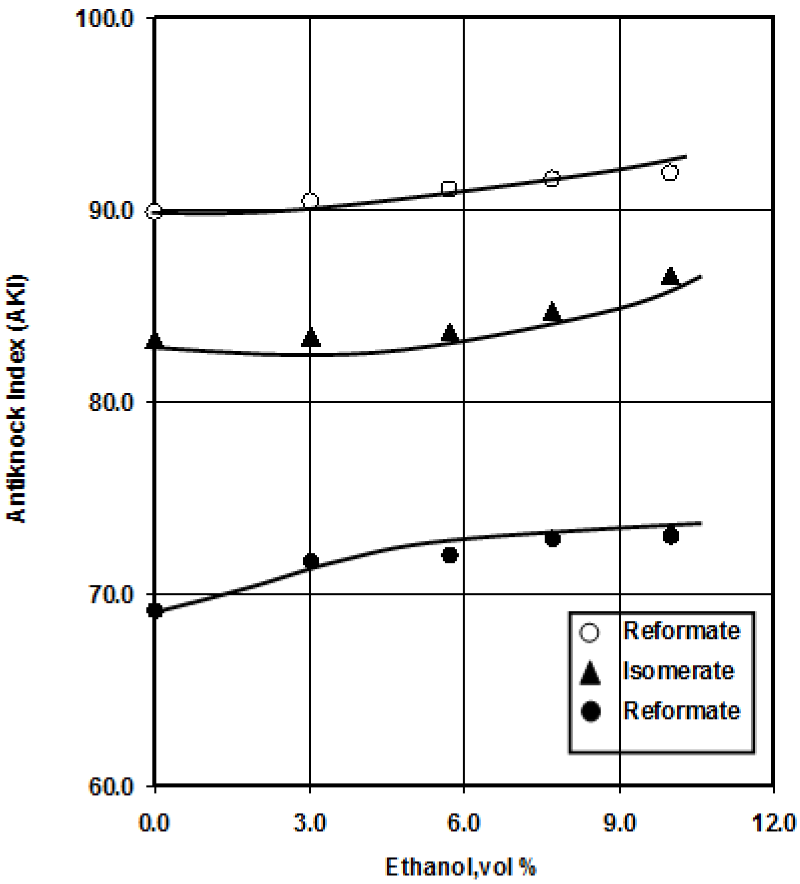

Figure 4- Effect of Added Ethanol on Antiknock Index (AKI) of Three Gasoline Refinery Streams.

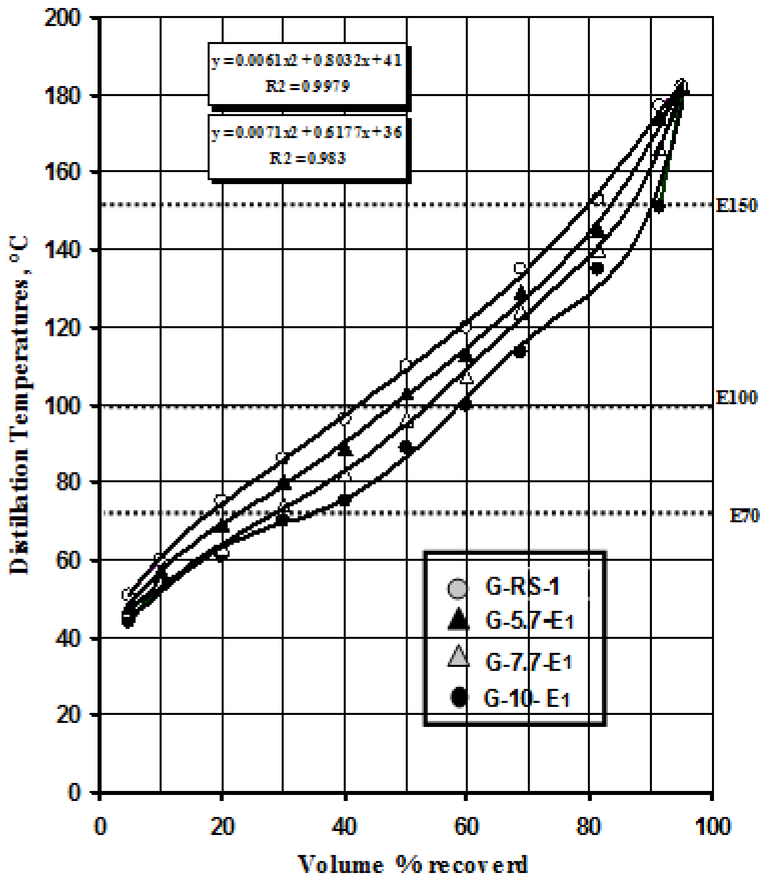

Figure 5 - Effect of Added Ethanol on Distillation Profile and Volatility Criteria of Gasoline G-RS-1.

CONCLUSION

1. When ethanol was added with gasoline, the characteristics of the mixture into which it was blended, was significantly modified due to the ability of ethanol to form azeotropes with gasoline hydrocarbons.
2. The principal changes in the fuel properties due to the addition of ethanol to gasoline include: increased octane number, greater fuel volatility and altered driveability score as indicated by the Driveability Index (DI).
3. Addition of ethanol oxygenate to hydrocarbon gasoline enleaned the fuel-to-air mixture of gases combusted in an engine. This leaning effect resulted in decreased tailpipe exhaust emissions of carbon monoxide (CO) and hydrocarbons (HC).
4. When 5.7% by volume ethanol was blended with three gasoline having different compositions, Co emissions were lowered by 19.7, 19.2 and 18.1% and HC emissions were reduced by 18.7, 18.9 and 21.7% as compared with the corresponding non-ethanol blends. NOx emissions were variable.

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