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Effect of Ethanol–Gasoline Blends on Fuel Properties Characteristics of Spark Ignition Engines

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Abstract: This paper investigates the effect of ethanol-gasoline blends on fuel properties characteristics of variable speed spark ignition (SI) engines using standard laboratory methods. Fuel properties tests were conducted for density, API gravity, kinematic viscosity, cloud point, flash and fire point, heat value, distillation and Octane number using ethanol-gasoline blends with different percentages of ethanol. The blends selection was based on successful completion of engine standard short test carried out on a computerized four cylinders, four stroke, and variable speed SI engine with eddy current dynamometer and data logging facilities. Fuel properties test results showed that blends densities and kinematics viscosity increased continuously and linearly with increasing percentage of ethanol, while API gravity and heat value decreased with decreasing percentage of ethanol. Furthermore, cloud point, flash and fire points for blends were found to be higher than pure gasoline fuel, while distillation curves were lower. The tested blends Octane rating based on Research Octane Number (RON) increased continuously and linearly with increasing percentage of ethanol. Results from this study will be valuable on the assessment of the suitability of ethanol-gasoline blends as bio-fuel for automotive industry to cater for the country needs.

Keywords: *Spark ignition engine; Bio-fuel; Ethanol; Fuel properties characteristics.*

1. INTRODUCTION

Bio-fuel initiative has been backed by government policies in the quest for energy security through partially replacing the limited fossil fuels and reducing the threat to the environment from exhaust emissions and global warming. The main fuel resulting found to be an increasingly important alternative to petroleum is bio-fuel. It is biodegradable, and produces significantly less air pollution than the fossil fuel. The fossil fuel exhaust is a potential carcinogen, since the use of bio-fuel has been found to reduce risks of cancer because it reduces the production of cancer-causing compounds, such as carbon monoxide. Bio-fuel also produces less greenhouse gases such as CO_2. When either bio-fuel or petroleum is burned, the carbon content of the fuel returns to the atmosphere as CO_2. Plants grown to make ethanol for bio-fuel draw CO_2 out of the atmosphere for photosynthesis, causing a recycling process that result in less accumulation of CO_2 in the atmosphere. Thus, bio-fuel does not contribute to global warming in the same way that petroleum does.

Many researchers have reported on ethanol-gasoline blends engine performance and emissions characteristics. Rice *et al.* [1] found little difference in power performance, specific fuel consumption, and thermal efficiency between engines fueled with gasoline or a gasoline blend of 15% ethanol (E15). A research study at Southern Illinois University found that with bio-fuel blends engine power and specific fuel consumption slightly increased [2]. Bio-fuel was also found to produce lower exhaust carbon monoxide and hydrocarbons with some difference between the NOx and smoke emissions of gasoline fuel and bio-fuel. The gasoline fuel replacement is regulated by the amount of ethanol in the blend. However, problems arise, due to the presence of water in the blend because commercially available ethanol is seldom found in an anhydrous state [3]. The commonly available ethanol grades contain between 10% and 20% water. Typical local distillation converts fermented sugar molasses to 190-proof or industrial ethanol, containing 5% water, and removing the remaining water requires special measures at added cost [4]. Thus, there would be an economic incentive if the spark ignition engine could be run on industrial ethanol instead of anhydrous ethanol. Johnsen and Schramm [5] investigated the low-temperature miscibility of ethanol gasoline-water blends in flex fuel applications at -25 and -2°C. It was found that the blend can be successfully used without phase separations within the tested temperature range. The performance and pollutant emissions of a four stroke SI engine operating on ethanol-gasoline blends of 0, 5, 10, 15, and 20% ethanol using artificial neural network was investigated by many researchers [6]-[8]. They found a decrease in CO and HC emission with the introduction of ethanol into gasoline.

The use of E85, a mixture of 85% ethanol and 15% gasoline, for flexible fuel vehicle's (FFV) has become common. Blends with other ratios of ethanol in gasoline are commonly used in various countries around the world, especially Brazil (up to 25 %), Australia (officially 10 %), Canada (10 %), USA (up to 10 %), and Sweden (5 %). There is still debate about whether, how and to what extent ethanol in gasoline may affect the materials in the vehicle and cause excessive wear of parts in the fuel system and the engine. However, in the USA, automotive industry has agreed that use of gasoline with up to 10 % ethanol will not affect the warranties of their vehicles [9], [10].

The problem however lies in other aspects surrounding the use of ethanol-gasoline blend. Ethanol has some lower fuel properties characteristics when compared to gasoline. The effect of blending these two fuels at different ratios on performance, serviceability and service life is not been known. There is considerable dearth of knowledge on fuel properties of various ratios of ethanol-gasoline blends. Many trials and development exercises have been carried out in many countries around the world but very little data are available. Although there has been a wide spread call for production of ethanol for engine fuel, the performance of the engine with this fuel seems not to have been mastered by the automotive industry. The call for ethanol bio-fuel seems to be politically motivated and is aimed at fuel economy, decreasing dependence on fossil fuel, environmental sanitation and less at machine life and performance. Ethanol has unavoidable anti fuel characteristics such as moisture, lower heat of combustion and a high flash point. What are, therefore, the effects of the various blends on these characteristics and what is the best suitable mixture.

Sugarcane production is mostly focused in Sudan and backed up by large investments in new sugarcane schemes. Across Kenana, Assalaya, Sennar, New Halfa and Gunied schemes, sugarcane production is more than 7.5 Million Tons annually. Utilization of ethanol alcohol fermented from surplus sugar molasses in sugar industry as bio-fuel in the Sudan is very encouraging and promising. These alternative fuels have the potential to be a very large agriculture produced commodity. Given the non-renewable of petroleum and agricultural potentials of the Sudan, it will be very important and attractive to acquire the know how of using ethanol as a substitute to petroleum fuel. In 2009 Kenana Sugar Company (KSC), the Sudan's largest sugar producer, launched an ethanol plant. The plant was built by Dedini Industrias of Brazil having a cost of US$15 Million as a joint venture between the Ministry of Energy, KSC, and GIAD Automotive Group. The plant is expected to produce 65 Millions Litres annually and to increase the production to 200 Million Litres by 2012. Sudan's sugar industry started to create a bio-fuel source for Sudan whose economy is largely dependent on crude oil. It lost almost 350,000 barrels per day after the cessation of the South Sudan. To date the arrangements to introduce ethanol in Sudan as a bio-fuel for automotive engines is limited. Consequently, the use of the ethanol as bio-fuel should be advocated strongly for research and development as well as a quick and subsidized market introduction.

The purpose of this study is to investigate the effect of ethanol-gasoline blends on fuel properties characteristics of a variable speed SI engine. Specific objectives are:

- To determine the properties of ethanol-gasoline blends such as density, API gravity, viscosity, flash and fire point, cloud point, heat value, and distillation and compare them with those of pure gasoline fuel.
- To determine Octane rating based on Research Octane Number (RON) for blends and compare them with that of pure gasoline fuel.

2. MATERIALS AND METHODS

Fuel properties experiments were carried out at the Central Petroleum Laboratories (CPL), Ministry of Petroleum, and at Petroleum and Gas Engineering Department laboratories, Faculty of Engineering, University of Khartoum. Engine tests were carried out at Blue Nile University, Faculty of Engineering Laboratories.

2.1 Fuel Blends

The ethanol (ethyl alcohol, C_2H_6O) was processed and supplied from Kenana Ethanol Alcohol Co. Ltd. The refined Kenana's ethanol alcohol was found to be colourless having concentration of 99.7% extracted from sugar molasses. Detailed description of the ethanol alcohol is presented in Table 1. Gasoline fuel was used as a reference fuel in this study. The gasoline fuel is a volatile, flammable liquid obtained from local fuel petroleum stations.

Blends preparations were produced simply by pouring gasoline and ethanol constituents into a container and mixing them. Up to 50% ratios in 5% increments by volume of the two constituents were prepared for fuels test samples. These micro-emulsions were found to be stable and homogeneous as no distinct phase separation was observed. For testing homogeneity, the blends were centrifuged with no signs of separation.

Blends selection was based on successful completion of the engine standard short test carried out on a computerized four cylinders, four stroke, and variable speed SI engine with eddy current dynamometer and data logging facilities (see Fig. 1). No modifications were made to the engine. For simplicity common fuel abbreviation system was adopted. The tested and selected blends are shown in Table 2.

Table 1. Detailed descriptions of Kenana's ethanol alcohol

Property	Value
Boiling point	78.5 ˚C
Heat of combustion	23.625 MJ/L
Heat of vaporization	33.74 kJ/mole
Octane rating	106 - 108
Stoichiometric air/fuel ratio	9/1
Concentration	99.6 – 99.8+
Acidity	≤ 30 mg/L
Water content	≤ 0.3
Density	0.789 g/cm^3 @ 20˚C
Point of humidity	< 6.5

Table 2. Tested fuels samples abbreviation

No.	Fuel	Abbreviation
1	100%gasoline (reference fuel)	Gasoline
2	90%gasoline +10% ethanol	E10
3	85%gasoline +15% ethanol	E15
4	80%gasoline +20% ethanol	E20
5	75%gasoline +25% ethanol	E25
6	70%gasoline + 30%ethanol	E30
7	65%gasoline +35%ethanol	E35

2.2 Fuel Properties Determination

Fuel properties of tested blends were determined in accordance with American Standard for Testing Materials (ASTM) procedures for petroleum products. Comprehensive analyses were carried out to document fuel properties of the tested blends. Each fuel sample was evaluated to determine the density, API gravity, viscosity, flash and fire point, cloud point, heat of combustion, and distillation. Figs 2-7 lists various apparatus employed in the determination of these fuel properties. The density of each tested sample was measured by hydrometer method (ASTM D287 Standard). The API gravity was calculated from density results. The kinematic viscosity was measured in Cannon-Fenske Opaque viscometer in accordance with ASTM D445. Flash and fire points were measured by Penskey-Marton apparatus (ASTM D93A).

Cloud and pour point was measured by Petrotest (ASTM D97 Standard). Heat of combustions was measured in record bomb calorimeter according to PARR 1266 standards, France (ASTM D240). The calorific value of the sample was determined by equating the heat generated to heat transfer to calorimeter. The distillation curve was determined by distillation device in accordance with ASTM D86.

2.3 Octane Rating Determination

The blends Octane rating was determined by a Cooperative Fuels Research (CFR) Engine (D2699). The test engine was a standardized single cylinder, four-stroke cycle, variable compression ratio and carbureted for the determination of Octane Number. It was manufactured as a complete unit by Waukesha Engine Division, Model CFR F-1 Research Method Octane Rating Unit (see Fig. 8). Table 3 lists detailed specifications of CFR engine, mechanical accessories and instrumentation.

Fig. 1. Engine test rig used for the tested blends

Table 3. Detailed specifications of CFR engine

Item	Specifications
Test Engine	CFR F-1 Research Method Octane Rating Unit with cast iron, box type crankcase with flywheel connected by V-belts to power absorption electrical motor for constant speed operation.
Cylinder type	Cast iron with flat combustion surface and integral coolant jacket Compression ratio Adjustable 4:1 to 18:1 by cranked worm shaft and worm wheel drive assembly in cylinder clamping sleeve.
Cylinder bore ,	82.25 (standard) mm
Stroke	114.3 mm
Displacement,	24083.8 mm^2
Lubrication	Forced lubrication, motor driven pump, plate type oil filter, relief pressure gauge on control panel
Cooling	Evaporative cooling system with water cooled condenser, Water shall be used in the cylinder jacket for laboratory locations where the resultant boiling temperature shall be 100 ± 1.5°C Water with commercial glycol-based antifreeze added in sufficient quantity to meet the boiling temperature requirement shall be used when laboratory altitude dictates
Mechanical accessories	
Fuel system (Carburetor)	Single vertical jet and fuel flow control to permit adjustment of fuel-air ratio
Ignition	Electronically triggered condenser discharge through coil to spark plug
Ignition timing	Constant 13° before TDC
Multiple fuel tank system with selector valving	
Intake air system with controlled temperature	
Instrumentation	
Knock Measurement System	Detonation pickup (sensor), a detonation meter to condition the knock signal, and a knock-meter
Detonation Pickup	Model D1 (109927) having a pressure sensitive diaphragm, magnetostrictive core rod, and coil.
Detonation Meter	

Fig. 2. Hydrometer instrument

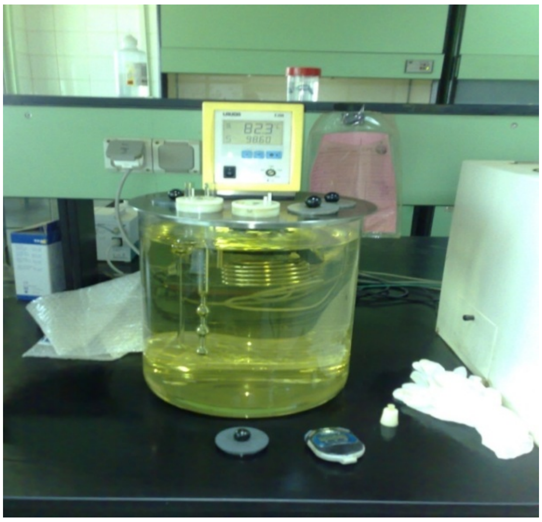

Fig. 3. Cannon-Fenske opaque viscometer

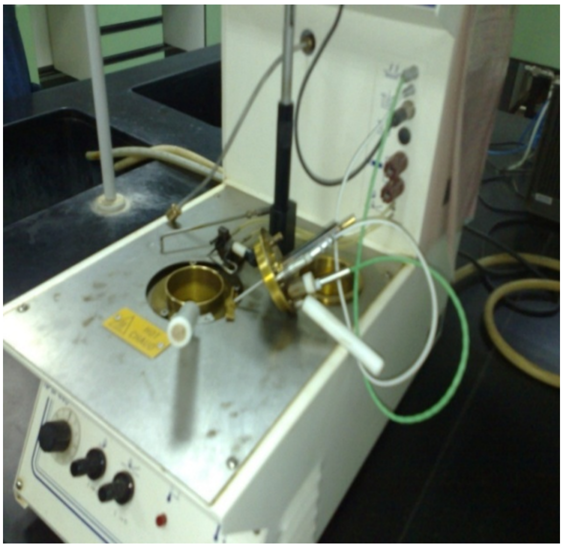

Fig. 4. Pensky-Martens cup apparatus

Fig. 5. Cloud point test apparatus

Fig. 6. Recording bomb calorimeter

Fig. 7. Distillation Device

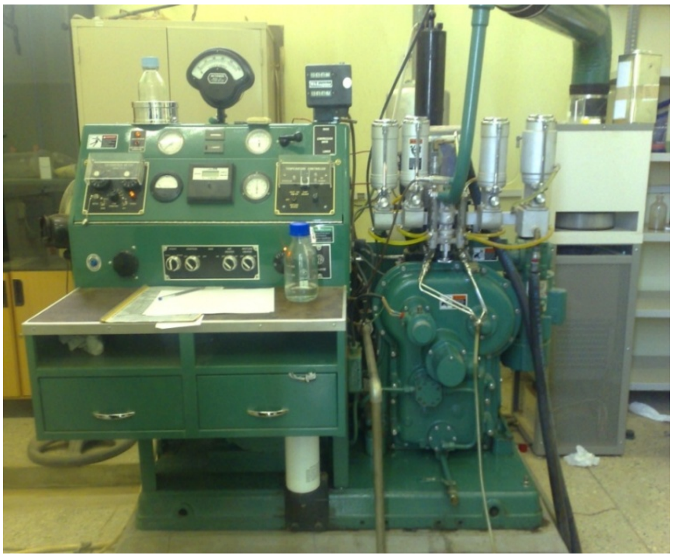

Fig. 8. Cooperative Fuels Research (CFR) Engine

The Octane rating of a sample of ethanol blend is determined by comparing its performance to that obtained with blends of iso-Octane and normal heptane. Iso-Octane is extremely knock resistant and has Octane rating assigned as 100, while normal hepatne is very knock prone and has assigned an Octane rating of 0. To measure the Octane rating of fuel sample, the sample is burned in CFR and the compression ratio is adjusted until the knock meter indicates that a standard level of knocking has been attained. A reference curve for this purpose was prepared by blends of n-heptane and iso-Octane. The air rate values for these blends were determined. The Octane rating of the tested fuel sample was obtained with interpolation from a guide curve. Entering these values into a coordinate system, a curve showing the dependence of air rate upon Octane number was realized.

3. RESULTS AND DISCUSSION

The tested blends fuel properties data are summarized in Table 4. The regression equations in terms of ethanol percentage are presented in Table 5. Discussion of the tested blends fuel properties, their variation and their significance are as follows:

3.1 Density (kg/L)

The average values of density for blends at a temperature of 15^{o}C are presented in Table 4. From the results it appears that the blend densities were found to vary from 0.7400 kg/L for gasoline to 0.7653 kg/L for E35. It was 0.12 % lighter than gasoline for E10 but 1.26 %, 1.87%, 2.25%, 2.9%, and 3.4%, heavier than gasoline fuel for E15, E20, E25, E30, and E35, respectively. The densities of blends were found to increase continuously and linearly by approximately 0.0008 for every increment of 1% ethanol (Table 5).

3.2 API Gravity

The average values of API gravity for blends at a temperature of 15^{o}C are presented in Table 4. From the result it appears that the blend API gravities were found to vary from 59.53 for gasoline to 55.21 for E35. It was 4.1%, 4%, 6.8%, and 7.3% for E10, E15, E20, E25, E30 and E35, respectively. The API gravities of blends were found to decrease continuously and linearly, approximately 0.1664 for every increment of 1% ethanol (Table 5). In general, API gravity decreases as the percentage of ethanol increases but it still within the range that can be handled by an internal combustion engine.

3.2 Kinematic Viscosity

The average values for kinematic viscosity of blends at 30°C are presented in Table 4. They were found to be 10.4%, 15.3%, 23.3% , 30.9%, 35.7% and 41% more viscous than gasoline fuel (0.4872mm^2/s) for blends E10, E15, E20, E25 , E30, and E35 respectively. Blends kinematic viscosities were found to increase continuously and linearly, approximately 0.006 for every,increment of 1% ethanol (Table 5). Viscosity is a measure of the flow resistance of a liquid. Fuel viscosity is an important consideration when fuels are carbureted or injected into combustion chambers by means of fuel system. If viscosity is too low, the fuel will flow too easily and will not maintain a lubricating film between moving and stationary parts in the carburetor or pump. If viscosity is too high, it may not be possible to atomize the fuel into small enough droplets to achieve good vaporization and combustion. In general the blends viscosities were within acceptable range for spark ignition engine.

3.4 Flash and Fire point

The average values of flash and fire points for blends are presented in Table 4. From the results, it appears that the blends flash point for E20, E25, E30 and E35 were 29.2, 30.0, 29.2 and 31 °C, respectively. The fire points were found to be 29, 29.1, 30, 32, 30 and 32 °C for E10, E15, E20, E25, E30 and E35, respectively, while the fire point of gasoline was 25 °C. However, E10, E15 and gasoline started to fire before determining its flash point. The flash point varies with the fuel volatility but is not related to the engine performance. Rather, the flash point relates to the safety precautions that must be taken when handling a fuel. Blends flash and fire points according to their values are above the standards values for handling and storage of gasoline fuels which has a flash point below the freezing point of water.

3.5 Cloud Point

The average values of the cloud points for the blends are presented in Table 4. From the results, it appears that the ethanol /gasoline blends cloud point for gasoline is -22 °C and above 8 °C for all tested blends. The cloud point typically occurs between 5°C and 8°C above the pour point. Cloud and pour points become important for heavier fuels in higher boiling range. Although, the pour-ability of gasoline is not a problem but it was specified in the guideline of fuel properties standards.

3.6 Heat of Combustion

The average values of gross heat content for the tested blends are presented in Table 4. The gross heat content of blends

Table 4. Fuel properties of the tested blends

Fuel blend	Density, kg/L @ 15.6 °C	API gravity, deg.	Kinematic viscosity mm^2/s@ 30 °C	Flash Point, °C	Fire Point , °C	Cloud Point, °C	Heat of Combustion , MJ/L	Octane number
Gasoline	0.7400	59.53	0.4872	_	25.0	-22	34.84	93.2
E10	0.7396	57.10	0.5383	_	29.0	> 8	33.19	97.1
E15	0.7495	57.09	0.5619	_	29.1	> 8	32.91	98.6
E20	0.7541	55.95	0.6007	29.2	30.0	> 8	32.43	100.4
E25	0.7571	55.21	0.6380	30.0	32.0	> 8	31.70	99.5
E30	0.7613	54.30	0.6614	29.2	30.2	> 8	31.53	102.5
E35	0.7653	53.50	0.6914	31.0	32.0	> 8	30.92	104.1

Table 5. Regression equations of tested blends fuel properties in terms of ethanol percentage

Attribute	Regression Equation	R^2
Density, kg/L	Y=0.0008X+0.737	0.9333
API, Deg	Y=-0.1664X+59.306	0.9826
Viscosity,	Y=0.006X+0.4814	0.9944
Heat Value, MJ/L	Y=-0.1069X+34.564	0.9775
Octane Number	Y=0.29X+93.75	0.9551

decreased by 4.7%, 5.5%, 6.9%, 9.1%, 9.5% and 11.3% compared to gasoline fuel (34 MJ/L) for E10, E15, E20 and E25, respectively. Blends heat values were found to decrease continuously and linearly, by approximately 0.1069 for every increment of 1% ethanol (Table 5). The decrease of heating values present in the blends was due to ethanol that has lower heat value of 23.625 MJ/L.

3.7 Distillation

Distillation curve shows the percentage of hydrocarbons that boil and distill at various temperatures. The results in Fig. 9 show the distillation curves for gasoline and blends E10%, E15%, E20%, and E25%. Due to time constrain only four blends were used in the distillation curve. Three points were take on the distillation curve to compare the distillation between blends and gasoline. The points T_{10}, T_{50}, and T_{90} refer, respectively, to the temperatures on the curve at which 10%, 50%, and 90% of the fuel has been distilled. At T_{10} the gasoline temperature is 60°C when 10% was distilled, the blends fuel E10%, E15%, E20%, and E25% decrease by 13.3%, 12.8%, 12.1%, and 12.5%, respectively with respect to gasoline temperature. The blends decrease by 22.5%, 25.5%, 24.2%, and 22.4%, respectively for T_{50} (95^{0}C), while increase by 11.7%, 10.3%, 9.7%, and 11.4%, respectively at T_{90} (145^{0}C).

It had been shown by many previous researchers that the presence of alcohol in gasoline depresses the distillation curve of fuel, which can cause problem with cold starting and vapour lock [11]. The expected trend was true of the four ethanol-gasoline blends. The distillation curve for each blend was compared to gasoline. The distillation curve for each blend was significantly depressed between T_{10} and T_{50} distilled. Adding ethanol to gasoline will increase the volatility, decrease the 50% distillation point T_{50} and affect the driveability index (DI). Furthermore, T_{10} must be sufficiently low to allow enough fuel to evaporate and form a combustible mixture. T_{50} point associated with engine warm up; a low T_{50} will allow the engine to warm up and gain power quickly without stalling. The T_{90} is associated with the crankcase dilution and fuel economy; if the T_{90} is two high, the larger fuel molecule will condensate on the cylinder liners and pass into the lubricating oil in the crankcase instead of burning [12].

3.7 Octane Number

The average values of blends Octane number are presented in Table 4. They were found to be 4%, 5.4%, 8.08%, 6.33%, 9.7% and 11.6% higher than that of the gasoline fuel (93.2) for blends E10 , E15 , E20 , E25, E30 and E35, respectively. Blends Octane ratings were found to increase continuously and linearly, approximately 0.29 for every increment of 1% ethanol (Table 5).

The Octane rating is a measure of the knock resistance of fuel. Yamin *et al.* [13] investigated the effect of ethanol addition to low Octane Number gasoline, in terms of calorific value, Octane Number, compression ratio at knocking and engine performance. They blended locally produced gasoline (Octane Number 87) with six different percentages of ethanol, namely 10%, 15%, 20%, 25%, 30%, and 35% on volume basis. They found that the Octane Number of gasoline increased continuously with the ethanol percentages in gasoline. They reported that the ethanol was an effective compound for increasing the value of the Octane Number of

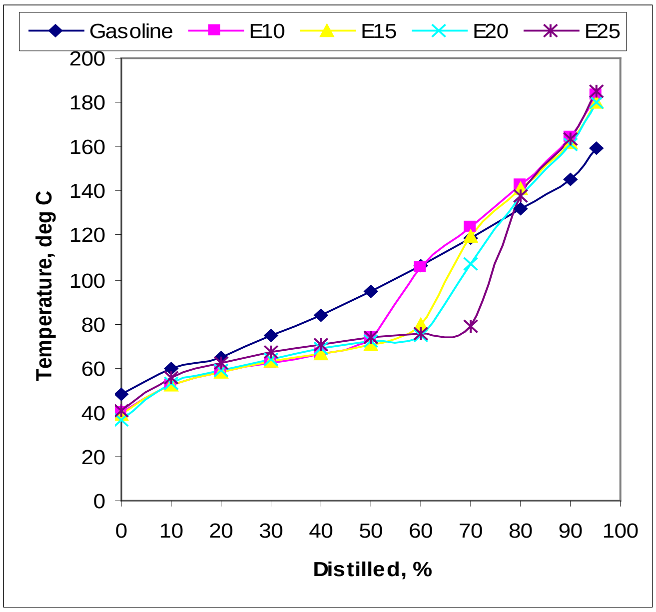

Fig. 9. Distillation curves of the tested blends and gasoline

gasoline. They also found that the engine performance improved as the percentage of ethanol increased in the blend within the range studied. As mentioned before, ethanol has a lower heating value than gasoline, which will reduce the energy content of the fuel. However this can be partly offset by the higher Octane Number of ethanol.

Many additives have been developed to improve the performance of petroleum fuels to increase the knock resistance and raise the Octane number. Fuel refiners were able to use a wide variety of lower Octane hydrocarbons in gasoline and then used TEL (tetraethyl lead) and MTBE (methyl tertiary butyl ether) additives to boost Octane ratings to acceptable levels. More recently, the oxygenated and Octane enhancing benefits of ethanol have been highlighted as a potential substitute for Methyl Tertiary Butyl Ether (MTBE), an oxygenated additive used to enhance the Octane and also reduce the CO emissions. However, TEL poisons the catalysts in catalytic emission control systems, and MTBE has proved to be highly toxic even in small quantities when it contaminates groundwater. Finally, detailed descriptions of engine standard short test procedures, analysis of engine performances, combustion, and emissions characteristics is beyond the scope of this paper. However, a prolonged engine testing is required to verify the suitability of the ethanol-gasoline blends for SI engines.

4. CONCLUSIONS

The following conclusions could be drawn from this study:

- Ethanol-gasoline blends can be used as an alternative fuel for variable speed spark ignition up to 35% blends without engine modification.
- Fuel properties of the tested ethanol-gasoline blends such as density and viscosity increased continuously and linearly with increasing percentage of ethanol while API gravity and heat value decreased with decreasing percentage of ethanol increase. Furthermore, cloud point, flash and fire points were found to be higher than pure gasoline fuel, while distillation curves proved to be lower.
- The tested blends Octane rating based Research Octane Number (RON) increased continuously and linearly with the increasing percentage of ethanol.

Based on the results obtained during this study work it can be suggested that:

- Comprehensive and extensive testing on fuel properties, engine performance, combustion, and emissions characteristics of ethanol-gasoline blends on SI engines should be conducted for long time.
- Research collaboration should be undertaken with sugarcane industry, and GIAD Automotive Group regarding using ethanol as bio-fuel for SI engines.

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