Review Article: Ethanol Gasoline Blends In SI Engine

Arjun U, Eldho Varghese, Jobin G. Pandichery, Joseph M. P., Renjith Krishnan M., Sreekanth S. Pazhoor, B. Baiju
Dept. of Mechanical Engineering
College of Engineering, Trivandrum

***Abstract*— Ethanol being a bio-renewable fuel can be blended with gasoline to use in SI engines. Some special characteristics of ethanol such as high octane number, high heat of evaporation, oxygen content in its basic form, anti- knocking properties and lower emissions favour the use of ethanol-gasoline blends. In this review, different ethanol- gasoline blends containing different volume % of ethanol are studied. Engine performance and emissions are analysed.**

It was found that torque output and combustion efficiency are improved, even though specific fuel consumption is increased. CO, HC, NO_x emissions are decreased due to the leaning effect and cooling due to higher heat of evaporation. The emissions of particulate matters and carcinogenic pollutants also reduced with the use of ethanol-gasoline blends.

Keywords—component; formatting; style; styling; insert (key words)

I. Introduction

Ethanol has been used in automobile engines since the nineteenth century, but was eventually replaced by the cheaper petroleum- based gasoline. The depletion of fossil fuel and the increasing global warming turned many countries attention to bio energy. Ethanol-gasoline blended fuels applications in SI engines have been studied by many researchers. Ethanol is having anti-knock capability and lower emissions of CO and UHC.

Bio-ethanol is renewable, and it can reduce greenhouse gas emissions. Bio ethanol can be produced from various kinds of biomass such as corn, sugarcane, sugar beet, cassava, and red seaweed. It is one of alternative fuels most employed because of its oxygen content which favours the further combustion of gasoline.

Besides, gasoline blends well with ethanol, compared to diesel, resulting in lower sulphur and aromatics content, higher octane number, and higher vapour pressure compared to the base fuel. The RVP (Reid Vapour Pressure) of ethanol is 17 KPa, far lower than 53.7 KPa for gasoline. But their mixture does not have a lower RVP value instead of that a volume fraction of 5-10% ethanol can achieve the maximal RVP and thus facilitate cold-start. Furthermore, the octane number of ethanol is in the range 106-110 which is higher than that of gasoline. Therefore, by increasing engine compression ratio, both the efficiency and power can be increased. It was found that the octane number had an increment of five and the engine output increased 5% for every 10% ethanol addition to gasoline.

Blending ethanol with gasoline permits a higher compression ratio without knock occurrence. New concepts like homogeneous charge compression ignition (HCCI) and dual-injection can also be applied to these blended fuels.

One major objective of using ethanol gasoline blended fuel is its ability to lower the emissions of CO and UHC. Alexandrian and Schwalm found that air/fuel ratio variation greatly influenced CO emission and, under fuel-rich conditions, CO and NO_x emissions could be reduced with blended fuels.

II. Tested Fuels

Different ethanol-gasoline blends having different ethanol percentages like E10, E20, and E30 etc. are tested and compared with the results of pure gasoline (E0).

Pure ethanol has lower A/F mass ratio and heat value, but energy content for unit mass of stoichiometric mixture ($H_{st, mix}$) is quite similar and therefore engine power is not affected by fuel composition. The cooling effect due to the higher ethanol heat of vaporization (H_v) is an added advantage. As a consequence some positive effect on volumetric efficiency is expected at ethanol percentage increasing. Moreover grams of CO_2 per MJ produced are not influenced by oxygenated compounds at the same engine efficiency.

A. Fuel Properties [5]

Table 1. Fuel properties

Fuel	Molecular Formula	Molecular Weight(Kg/ Kmol)	Octane Number
Gasoline	C_7H_{17}	100-110	91-96
Ethanol	C_2H_5OH	46	106-110

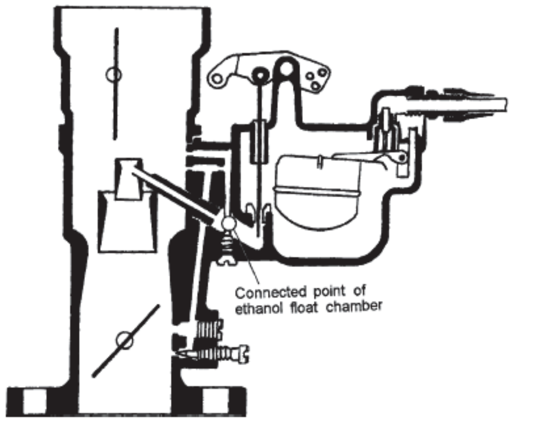

Fig 1.Schematic diagram of Carter carburettor. [6]

B. Characteristics Of Tested Fuels [3]

Table 2. Characteristics of tested fuels

Fuel	A/F (Kg/Kg)	Heat Value (Mj/Kg)	Density (Kg/ M^3)	Cooling Effect* (^{O}c)	H_{stmix} – Heat Content Of Stoichiometric Mixture (Mj/Kg)	H_v – Heat Of Vaporization (Mj/Kg)
Gasoline	14.3	42.7	750	24	2.78	349
E10	13.8	41.0	754	30	2.78	409
E20	13.2	39.4	757	35	2.77	468
E30	12.7	37.8	761	42	2.76	527
E85	9.8	29.2	780	86	2.71	840
Ethanol	9.0	26.9	785	102	2.69	923

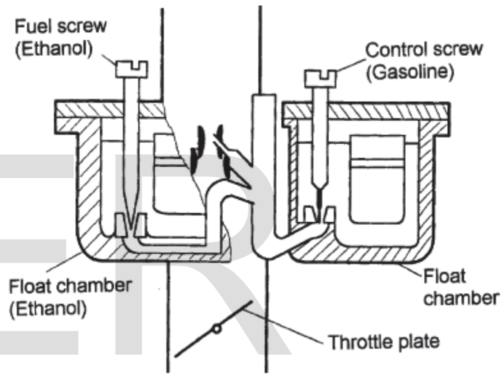

Fig 2.Schematic diagram of redesigned carburettor. [6]

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III. Engine Modifications

A. New carburettor

Bedri and Fikret observed a phase separation in gasoline–ethanol mixtures when the amount of water present in the mixture is over a certain limit [6].Gasoline, which contains less than 20% ethanol by volume and aromatic in character, is said to be more stable. For gasoline–ethanol mixtures to be used as a motor fuel the mixture must be stable and a phase-separation should not occur. In gasoline–ethanol–water systems, the phase separation depends on the methanol and water content of the blend, the environmental temperature, and the composition of gasoline [6]. In order to reduce the phase separation temperature, higher aliphatic alcohols such as tertiary butyl alcohol, benzyl alcohol, cyclo-hexanol or toluene are usually added to the gasoline– alcohol blends and the carburettor was redesigned to be able to use gasoline–alcohol mixture as a fuel. The new carburettor had two float chambers is shown in fig 2, one used as an ethanol tank while the other used as a gasoline tank. Connection point of the ethanol float chamber with the original carburettor is shown in fig 1.

With the use of new carburettor system, the consumption of two different fuels, which made phase transformation, was secured. Gasoline and ethanol was mixed in the fuel discharge tube. In the case of idle speed, the fuel was taken only from gasoline float chamber when the throttle plate position was increased and also the ethanol amount in the mixture was increased.

IV. Effects On Engine Performance

A. Cooling Effect

Ethanol has higher latent heat of vaporization than that of gasoline. So more heat is required to vaporise the fuel mixture of alcohol and gasoline. This causes a reduction in the exhaust gas temperature when blends are used [1]. In addition, the heat release of gasoline is higher than those of the blends after the 30o crank angle. This is thought to be the reason of the exhaust gas temperature of gasoline being higher than those of the blends.

B. Combustion

No appreciable differences in combustion development were found, while a slightly better global efficiency (about +5% as mean values) was achieved with E85 [3].

The better efficiency with E85 was also confirmed by a mean CO_2 improvement of 7% for E85 vs. gasoline. The global efficiency of E85 estimated from the lower heating values was found to be 4% higher than that of gasoline even though the combustion efficiency did not change with the fuel. Therefore the efficiency improvement could be due to some other reasons such as a lower compression work (for lower intake temperatures due to cooling effect) and lower thermal losses (for lower maximum in-cylinder temperatures) [3]. Combustion analysis carried out by measuring in cylinder pressure confirms that fuel does not influence combustion quality [3].

With spark advance optimization in each operative condition, no great differences among the pressure cycles of the different blends can be observed.

Intake and exhaust pressures did not differ for the tested fuels since throttle angle is almost similar. Same behaviour was observed for the burned mass fraction, being both incubation time of combustion and main duration combustion substantially the same for all the tested fuels, with the exception of E85 blend which is having a slightly faster combustion.

C. Peak Pressure

The peak pressure was found to increase with ethanol addition and is maximum for E10 when compared to pure unleaded gasoline. However, ethanol percentage above 10% results in a decrease of the maximum pressure to a value even lower than that of E0 [9]. This explains as the addition of ethanol to gasoline results in:

(1) An increase of the octane number.

(2) A decrease in the heating value.

These effects have opposite results in terms of engine performance. The first effect dominates up to an ethanol percentage of 10%, after which the second effect starts to take over.

D. Power Output

In general, torque with blended fuels (E50 and E85) were higher than that of base gasoline. Even though the ethanol addition to the gasoline decreases its heating value, the increase in torque and power were obtained [8]. This is explained with several reasons. The leaning effect of ethanol as it is an oxygenated fuel is a possible reason for more complete combustion, thereby increasing the torque. Due to the higher density of ethanol a larger amount of fuel for the same volume is injected to the cylinder. This results in increase in torque and power. And finally, the latent heat of evaporation of blended fuels is higher than that of base gasoline; this provides lower temperature at intake manifold and increases volumetric efficiency. The charge into the cylinder directly affect on torque and power.

E. Knocking

Ignition timing variations, causing detonation, with compression ratio at 2000 rpm is shown below.

Sound of detonation could be heard at low speeds, particularly when increased in advanced timing. At the same time the knock formations were observed on oscilloscope screen. In the experiment performed with E40 and E60 ethanol blends were not observed knock formations with MBT ((Maximum Brake Torque timing) [7].

When the ignition timing increased above the MBT, the knock phenomena can be seen with E40 and E60. Higher octane number of ethanol and blends compared with gasoline yield better detonation resistance [9].

F. Thermal Efficiency

Although thermal efficiency of the engine showed no significant change relative to gasoline, the advantage of increased octane number could well be used in increasing the efficiency when the compression ratio of the engine was altered.

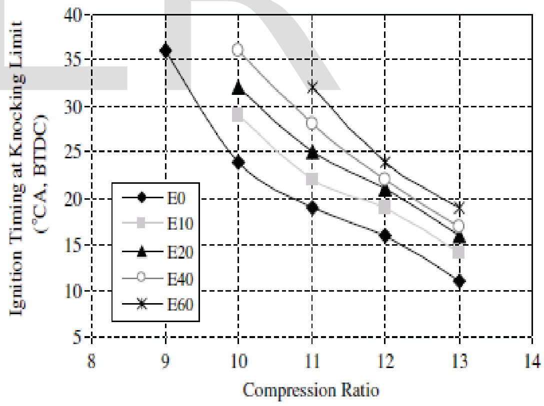

Fig 3.Variation of detonated ignition timing vs. compression ratio (engine speed: 2000 rpm). [9]

G. Fuel Consumption

It is well known that heating value of fuel affects the BSFC (brake specific fuel consumption) of an engine. The lower energy content of ethanol–gasoline fuel causes some increment in BSFC of the engine when it is used without any modification. The increment mainly depends on the percentage of ethanol. The heating value of ethanol is approximately 35% less than the values of gasoline. More blends are needed to produce the same power at the same operating conditions due to its lower heating value in comparison to base gasoline (E0). As a result, BSFC increases. Also, it was determined that the reduction in BSFC values at higher compression ratio is lower than those of lower compression ratio. Increasing BSFC due to lower energy content of ethanol–unleaded gasoline blends may be improved by increasing compression ratio for a fixed engine speed, a higher throttle opening can provide more fuel for burning, i.e. more energy input. Therefore, the torque output is increased with the increase of the throttle valve opening. The theoretical AFR of gasoline is 1.6 times that of ethanol; therefore the specific fuel consumption (sfc) should be increased with the increase of ethanol content.

V. EFFECTS ON EMISSIONS

Ethanol contains an oxygen atom. Therefore it can be treated as a partially oxidized hydrocarbon. When ethanol is added to the blended fuel, it can provide more oxygen for the combustion process and this is called ''leaning effect''. This leaning effect decreases CO emission tremendously due to more complete combustion. HC and NOx emissions will also decrease under certain operating conditions.

A. CO & HC Emissions

CO and unburned hydrocarbon emission among the exhaust gases represent lost chemical energy due to incomplete combustion. CO concentrations are greatly dependent on the operating air fuel ratio relative to the stoichiometric proportions. It is a product of incomplete combustion due to insufficient amount of air in the air–fuel mixture or insufficient time in the cycle for completion of combustion [7].Ethanol being an oxygenated fuel contains an oxygen atom in its basic form. When they are added to the fuel, they can provide more oxygen for the combustion process and lead to the so-called "leaning effect". Due to the leaning effect, CO emission decreases significantly. That is maybe the reason of CO reduction.

Unburned HC emissions are from unburned mixtures, which is due to improper mixing and incomplete combustion. UHC results in photochemical smog and ozone pollution. Generally, the main sources of unburned HC emissions are misfires, exhaust valve leakage, liquid fuel effects (especially during cold start and warm-up) and fuel or fuel/air mixture protected from the combustion process in crevices, oil films and deposits [1].

HC emissions decrease with the increase of ethanol content in the fuel blend for the most test conditions. It was observed that increasing the ethanol content, the concentration of HC emission decreases in comparison to base gasoline (E0) [7]. The lowest HC emission was obtained with E85 fuel operation while the maximum HC emission with E0.

B. CO_2 Emissions

Carbon dioxide (CO_2) is one of the basic greenhouse gases, which is produced by the complete combustion of hydrocarbon fuel. CO_2formation is affected by the carbon hydrogen (C/H) ratio in the fuel. The main reason of this decrease is thought that C/H ratio and C content of ethanol is lower than gasoline. In some cases, CO_2emission increased with the increase of ethanol fraction in the fuel blends. Ethanol is having lower heating value than that of gasoline. Therefore, more oxygenated fuel is required to obtain the same brake power from the engine. Injecting more fuel may cause increasing of CO_2 emission.

C. NO_x Emissions

A mixture of nitric oxide (NO) and nitrogen dioxide (NO_2) are formed by the oxidation of nitrogen from the air in the combustion process. The formation of NO_x is strongly related to the peak temperatures achieved during combustion, the oxygen concentration and residence time for the reaction to take place. If the concentration of NO_x is above certain level and reactive hydrocarbons are also available in the atmosphere, smog is generated under strong sunlight. It is seen that there is a decreasing tendency in NO_x emissions with the use of the ethanol blends as compared to pure gasoline.

With the use of alcohol in gasoline, the combustion temperature is decreased due to high latent heat and corresponding cooling effect. In addition to that their lower heating value and oxygen content leads to the reduction in NO_x emissions [1].

D. Particulate Matters

At the same engine load, PN emissions decrease on ethanol addition and are minimum for E85 [3].The PN reduction percentage of alcohol blends respect on gasoline ranges between 30% and 95% whereas the PM_1 between 10% and 98% [3].

E. Unregulated Organic Emissions

Emissions of carbonylic compounds, VOC and PAHs were measured with gasoline, E10, E20, E30 and E85 over the high load engine experiments [3].

The carbonylic emission increases when alcohol percentage in gasoline increases. For E10, E20 and E30, the carbonylic sum is almost twice that of gasoline; for E85 this ratio becomes almost 3.5. The use of oxygenated fuels provides high carbonylic compound emissions; the strong increment compared to gasoline (almost 3.5 times higher) was measured for E85 blend and is mainly due to acetaldehyde [3]. For alcohol content ranging between 10 and 30 vol. %, the carbonylic sum becomes almost twice that of gasoline.

A 50% reduction of benzene and 1,3-butadiene emissions, classified as carcinogenic to humans was achieved with E85 blend. Concerning PAHs, B(a)P and toxic equivalent evaluated for alcohol/ gasoline blends reduce between 30% and 70% compared to gasoline. Also for this class of compounds, the best result in terms of PAHs emission reduction is obtained with E85 blend.

F. Soot Formation

Soot is naturally low from the stoichiometric combustion that occurs in spark ignition engines, and since 3- way catalysts efficiently limit hydrocarbon emissions. However, the situation is changing due to the new development: That is the introduction of gasoline direct injection (GDI) engines, which aim to improve fuel efficiency. GDI engines offer a number of opportunities for improved fuel efficiency, such as reduced pumping losses, charge air cooling, and downsizing when turbocharged. But, direct injection of fuel into the engine cylinder is susceptible to incomplete fuel evaporation and to fuel impingement on piston and cylinder walls, both of which lead to combustion of liquid fuel and, consequently, to increased PM emissions [10]. The four flames examined in this study display qualitative similarities in the evolution of soot size with height in the flame as well as distinct differences. Although there is a slight gradation towards a yellower colour, the E0, E20, and E50 flames are clearly alike, whereas a marked change occurs for E85.

Addition of small quantities of ethanol to gasoline has little effect on these flame properties; thus, size distributions recorded along the E20 flame are remarkably similar to those for E0. the primary particles constituting soot agglomerates from the E85 flame are less than half the size of their counterparts in the E0 flame.

G. Cold Start Emissions

During an SI engine start up, fuel-rich injection is needed to ensure ignition. This oversupply of fuel and the non-functioning of catalytic converter due to its low temperature produce the large amount of HC and CO emissions in the cold-start period. The total amount of emissions associated with various ethanol gasoline blends during the cold-start period were collected and analysed to determine the effect of ethanol addition on cold-start emissions.

E5 and E10 performed almost indistinguishably from the gasoline (E0), while E20 - E40 clearly decreased HC, CO and NO emissions. the combustion of ethanol gasoline blends was monitored for various equivalence ratios in a constant volume chamber. They concluded that for E30, during the cold-start period, the emissions of CO, HC, and NOx could be reduced by 60%, 40%, and 20%, respectively, from the emissions from gasoline burning [2]. At 120 s, E30 had about 50%, 20%, and 10% reduction in CO, HC, and NOx from those of E0. HC and CO decreased due to the more excess air for more ethanol in the ethanol gasoline blends as mentioned above. NO decreased probably also due to the excess air, which lowered the combustion temperature. The engine speed was not stable for E40. Although the irregularities on the curve seem light, in reality, the poor combustion caused considerable vibrations. In the long run, the vibrations could be very harmful to the engine parts, E40 is therefore not recommended for cold starting. In conclusion, the ethanol content in gasoline for best cold start emissions was determined to be at least 20 per cent but no greater than 30 per cent [2].

VI. CONCLUSIONS

The conclusions that have been drawn after completing a review on ethanol- gasoline blend fuels are as follows:

Torque produced with blended fuels were generally found to be higher than that of base gasoline in all the speed range due to higher latent heat of evaporation of ethanol and oxygenated nature of fuel. The combustion efficiency is also improved since the fuel is partially oxidized.

The brake specific fuel consumption of the engine shows an increasing trend due to the lower energy content of ethanol–gasoline fuel depending on percentage of ethanol in the blend.

HC emissions reduced significantly as a result of the leaning effect and additional fuel oxygen caused by the ethanol addition. But, HC emissions increased at higher compression ratio due to higher surface to volume ratio.

Reduction in NO_x emissions was obtained with ethanol addition due to the high latent heat of vaporization of ethanol and the resulting cooling effect. Higher NO_x emissions at higher compression ratios results from the higher maximum combustion temperature with the higher compression ratio.

It was also found that ethanol–gasoline blends allow increasing compression ratio without knock occurrence.

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