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Research Article

Blending of Ethanol in Gasoline:Impact on SI Engine Performance and Emissions

Amit Pal[Ȧ*]

[Ȧ]Deptt of Mechanical Engineering, Delhi Technological University, Formerly Delhi College of Engineering, Delhi, 110042

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Abstract

In this work the performance and emission characteristics of a 4 stroke, 4 cylinder spark ignition MPFI engine was investigated with different ethanol gasoline (Gasohol) blends. Ethanol can also be used in C. I. engines as ethanol blended (Desihol) diesel, but due to its easy miscibility with Gasoline and having a higher octane number, ethanol is preferably blended with gasoline. Due to the higher ethanol blend usability constraints, in this work the investigation was kept limited to the low (5-15 % ethanol) ethanol gasoline blends. The present paper aims at discussing the low ethanol gasoline blends and gasoline (E0/G100), which were tested on a Maruti Suzuki Wagon R engine with a SAJ eddycurrent dynamometer unit. The performance parameters like brake power and thermal efficiency and exhaust emission parameters like CO, HC, NOx and CO_2 were recorded. The results of this investigation prove the applicability of low ethanol blended Gasoline as clean fuel to reduce CO, HC and NOx emissions. Performance parameters show a marginal increase in BHP and thermal efficiency a little increase in specific fuel consumption, whereas the usefulness of the inherent oxygen content in the ethanol molecule has been proved through the occurrence of a higher peak cylinder pressure and a higher exhaust gas temperature.

Keywords: *Bio-Gasoline, Exhaust emissions, Ethanol blend, Performance testing, Gasohol*

1. Introduction

Despite discovery of new sources of unconventional sources of energy, due to inadequacies in the supply of other forms of commercial energy relative to demand, Gasoline remains the primary energy source in India and is preferred as an automotive fuel. It is evident that (MoPNG, GOI report 2011-12), its consumption has been increasing sharply from 3.5 Million Metric Tons (MMt) in the year 1950-51 to 84.3 MMt in 1997-98 to about 130 MMt in 2001 and it were about 175 MMt in 2006-07. Among the potential alternative fuels, ethanol is the most feasible alternate fuel in near future. The reasons for its preference in Indian scenario are following:

First, they can be produced from “cellulosic biomass”, such as trees and grasses or from different agricultural products. Thus they represent really a zero emission technique as they eat up a lot of CO_2 in the process of theirproduction.

Secondly, ethanol (CH_3CH_2OH) is made up of a group of chemical compounds whose molecules contain a hydroxyl group, OH, bonded to a carbon atom; so, the oxygen content of this fuel favours further combustion of gasoline. And most importantly these are home grown; therefore they not only reduce the burden of arranging the foreign currency but also generate a massive opportunity of rural employment generation.

The countries like Brazil, Sweden and USA have marked their presence in the Bio-Gasoline based alternative auto fuel sector by the invention of the flexible fuel vehicle technologies and application of ethanol gasoline blends as high as E85 to E100 (Frank et al. 1998), (Pikunas et al. 2003). The economic and environmental constraints have compelled a country like India to imply a compulsory utilization of just E10 as fuel in the light duty vehicles. While there is no shortage of sugarcane in India, which is one of the prime sources for automotive ethanol fuel, being the 2nd largest producer in the world, India still lacks the technological advancement in terms of engine modifications and material compatibility problems. Ethanol besides being a renewable bio–mass based alternative fuel has other added performance based properties like the higher octane number, inherent oxygen content, and a higher latent heat of vaporisation which allows a higher power to be extracted from the engine both in the modified and unmodified state.

The addition of the anhydrous ethanol fuel to gasoline merely is enough to reflect that the properties of the blend generated inclines towards those of ethanol fuel (Milan Pospisil et al. 2009), (Karabulut et al., 2009), (Black and Frank, 1991). Because of inherent oxygen content of about 3.5% in an ethanol molecule, when the blend powers an unmodified S I engine the overall blend mixture burns lean nearing a stochiometric A/F ratio of 17.2 (Agarwal, 2006), (Demirbas, 2006), (Brinkman and Norman, 1981). This is

*Corresponding author: **Amit Pal email: amitpal@dce.ac.in**

one of the chief contributing reasons to the increased power, thermal efficiency and peak cylinder pressures. The inherent oxygen molecule contributes to an increase in the research octane number of the blend. The higher Octane Number allows the compression ratio of the engine to be increased again contributing to a higher power output. Because of its chemical structure the alcohol molecule contains fixed oxygen. This results in a lower calorific value of 26.8 MJ/kg of ethanol as compared to 44.5 MJ/kg for gasoline and hence higher fuel consumption with gasohol fuel. A lower flame temperature reduces heat losses from the engine and increases the thermal efficiency. Ethanol's stoichiometric flame temperature is 2197 K as compared to 2266 K for gasoline, contributes to higher efficiency for a blend fuelled engine (Powell, 1975), (Kremer, 1996,).

The comparison of various properties of Ethanol and Gasoline fuel is summarised in Table 1. Ethanol has a wider flammability limit of 3.5-26 volume % as compared to 1.4-7.6 volume % for gasoline, and hence is on the richer side. A wide rich flammability limit may be useful because rich air: fuel ratios can be used to maximize power by injecting more fuel per charge. A wide flammability limit on the lean side is useful in extending the operating range of the lean burn engines. Gasoline is composed of a mixture of large number of hydrocarbons having boiling point ranging from 30^0C to about 200^0C. Ethanol in contrast has a BP of 78^0C. The alcohols lack the light end fractions essential for cold starting of SI engines (Kremer, 1996), (Fikret and Bedri, 2004). Although ethanol itself has an RVP less than that of Gasoline, its addition to Gasoline markedly increases the RVP of the blend, which can lead to increased evaporative emissions. It is generally accepted that the peak RVP of ethanol blends occurs at around 5-10% ethanol concentration, and is about 6.5% above the RVP of neat Gasoline (Murphy and McCarthy, 2004).

Table 1 The Comparisons of The Gasoline and Ethanol thermodynamic Properties

Properties	Ethanol	Gasoline
Chemical Formula	C_2H_5OH	mC_nH_{2n}
Boiling Point, deg C @ 1 bar	78	30-225
LHV,MJ/kg Fuel	26.8	44.5
Octane number (Recearch)	111	90-98
Octane number (Motor)	94	82
Stoichometric A/F, mass	8.94	15.04
Flammability limit in air vol%	3.5-26	1.4-7.6
Adiabatic flame temp, Kelvin	2197	2266
Auto-ignition temp, Kelvin	792	753
Molecular weight	46	112
Spacific Gravity at 15.5 ◦ C	0.794	0.71-.75
Latent heat of Vapourisation,kcal/kg	204	70-100
Flame velocity, cm/sec	48	43
Vapour pressure at 58 ◦C bar	0.21	0.8

Several problems associated with ethanol have however put a restriction on the use of ethanol gasoline blends with higher ethanol percentage.Pure ethanol has a moderate volatility. Its high boiling point (78°C) induces difficulties of vaporization in ambient or cold conditions. Moreover, as it has been outlined previously, as ethanol has a very high latent heat of vaporization (3 times higher than typical gasoline). This property induces driveability difficulties. Due to the increased RVP of the ethanol gasoline blends the volatility of the fuel becomes higher as compared to baseline gasoline. Under such conditions the increased vapour formation in the fuel tank and the fuel carrying hoses lead to hot startability and vapour lock problem. (Murphy and McCarthy, 2004]

Ethanol contains acetic acid that can corrode aluminium alloys. It also adsorbs the lead in alloys causing the surface to become porous. Ethanol can chemically attack some of the resins used to make fibreglass tanks causing them to dissolve. In doing so, the ethanol causes leaks, heavy black deposits on engine intake valves, and deformation of push rods, pistons, and valves. Once absorbed into rubber, the oxygen in alcohol fuels breaks the rubber's carbon-carbon double bonds in the rubber and embrittle the rubber and cause swelling. This problem is associated mainly with the rubber fuel hoses and the rubber gaskets, the carburettor bowl. An additional problem with rubbers in fuel systems is the temporary attachment of hydrocarbons in the rubber to the hydrocarbons of the fuel.

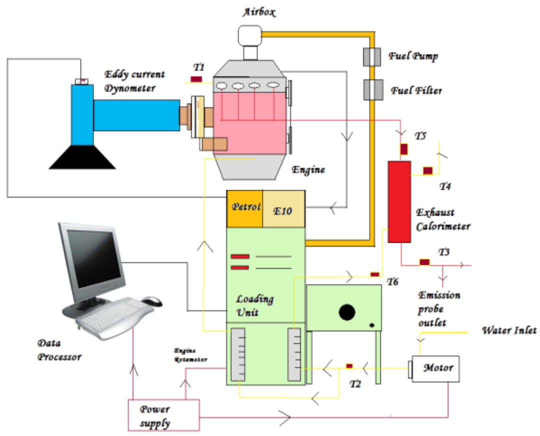

Figure 1: Schematic details of the test setup

As a result, the hydrocarbons in the rubber may add to a fuel's hydrocarbon content, creating increased emissions (Kumar et al. 2008). If too much water is introduced into an ethanol blend, the water and most of the ethanol (around 60% - 70%) will separate from the Gasoline and the remaining ethanol. Thus water being the densest of them all collects at the bottom of the fuel tank causing just water to be pumped to the carburettor leading to a momentary stalling of the engine (Murphy and McCarthy, 2004). Ethanolblends increase the solubility of the gum in gasoline and this may partly account for the increased intake system deposit-forming tendency. Dissolved gum causes suspended materials to plug filters. In order to overcome the above shortcomings and harness the advantageous potential associated with higher percentage of ethanol blended gasoline blends in an unmodified SI engine, some material changes may be incorporated. Viton B, Viton GFLT, Viton GF are all acceptable materials to be used in an ethanol vehicle. Nylon and Teflon components such as the fuel hoses that connected the main fuel supply to the main stainless steel fuel lines and the in-tank fuel pump reservoir are compatible with blends up to E85 (Sheehy,2010) and (Sriram Bata,1993). Compatible fuel injectors would be constructed of compatible polymers and Viton o-rings on the interior and exterior.

2. Objectives & Experimental Setup

The primary objective of the study is to investigate the performance and emissions of a standard S I engine originally designed to run on gasoline. The study is carried out with the following objectives:

- To study quantitatively the CO, HC, NOx and CO_2 emissions with different ethanol gasoline blends when engine is operated under E-5 to E-15 blends in comparison with the baseline gasoline.
- To investigate into the performance based parameters like thermal efficiency, brake power output and brake specific fuel consumption with different ethanol gasoline blends.

Experimental Setup

The experimental setup for the present work consists of the following: Maruiti Suzuki make 4 cylinder inline, 4 stroke gasoline engine with the following specifications as given in Table 2. Some additional components like, Saj engine dynamometer unit working on the eddy current principle with water cooing and loading unit, and AVL DiGAS 444, 5 gas analyzer for exhaust gas emission analysis. The schematic setup is shown in the Figure1. It is attached with necessary instruments for crank-angle measurements. These signals are interfaced to computer through engine indicator for pθ−pV diagrams. Windows based Engine Performance Analysis software package “Engine soft” is used for on line performance evaluation. Another important unit is the exhaust outlet unit which comprises of the outlet tailpipe, exhaust heat balance measurement unit and a secondary outlet for the fitment of the gas analyzer probe for emission measurement.

4. Materials and Methods

Gasoline used in the study was purchased from nearby IOCL Gasoline pump, while Ethanol (99.8% purity) was taken from local chemical supplier. Samples were prepared on volume % basis. Measurements for the performance and emissions parameters were taken at various loads.

Table 2: The Set up specifications

Characteristics	Value
Make	Suzuki
Cylinder	4
Power	44.5kW@5000rpm
Torque	59Nm@2500rpm
Bore	72mm
Displacement	1100mm

4. Comparative Performance & Emissions Curves for Gasoline & Ethanol Blends

Using ethanol blend in gasoline engine can favourably reduce fine particulate matter (PM), carbon monoxide and global warming. Here in this performance evaluation test we are showing different curves b/w load (kiloWatt) v/s thermal efficiency (%), Bsfckg/kWhr, CO (%), HC (ppm) and NO_xin ppm.

Brake Thermal efficiency v/s power

Figure 2 shows the results of thermal efficiency v/s power, ethanol blends of 7.5 to 12.5% gives the most optimum thermal efficiency, especially at higher power, the gains are more. Still the gain in absolute are small and a higher compression ratio is need to be investigated to utilise the anti knock characteristics of ethanol blends. Also an increase in the power may be attributed to the increased volumetric efficiency of the engine due to the higher latent heat of vapourisation of ethanol of 207 Kcal/kg as compared to 70-100 kCal/kg of gasoline. Also due to the higher latent heat of vapourisation the combustion temperatures for the blended ethanol fuel decreases and the amount of thermal load on the engine. Therefore for engines designed to run on gasoline, marginal thermalefficiency improvement can be obtained.

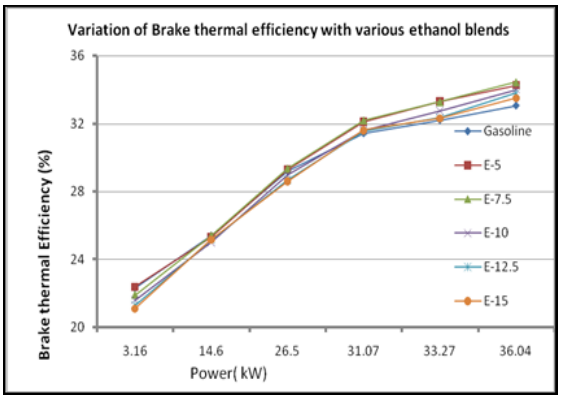

Figure 2: Variation of Brake Thermal Efficiency with Various Ethanol Blends

Brake Specific Fuel Consumption v/s power

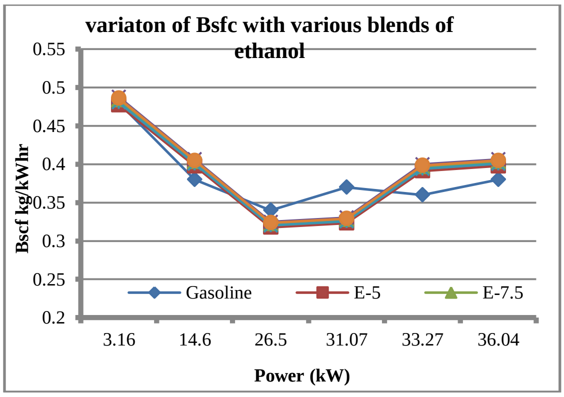

Figure 3: Bsfc v/s Power (Gasoline Ethanol Blend)

Considering the trend of bsfc v/s power, Figure 3 show that for all the ethanol blends the combustion efficiency improves but at higher blends bsfc increases slightly due to lower specific heat of the ethanol and this increase is significant at higher power. Though we have found an increase in bsfc with ethanol blends over gasoline when the engine was run at higher loads and this further increased with increase in blend % of ethanol.

CO emissions

The addition of ethanol to gasoline causes an increase in the oxygen available for combustion in the intakecharge thereby making the air fuel mixture lean in an unmodified engine, hence the charge burns more completely Use of ethanol blends in gasoline engines reduces the CO emissions vis-à-vis gasoline also at higher loads the drop in CO emissions is higher, this canbe seen from Figure 4. With E10 and above the combustion completed much earlier duringthe expansion stroke, thereby decreasing the probability of CO emissions due to flame quenching caused by downward movement of the piston.

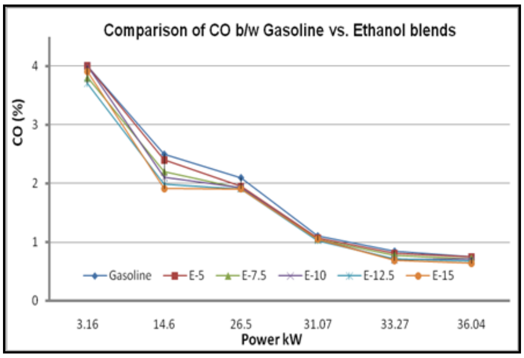

Figure 4: CO v/s Power for Gasoline Ethanol Blends

HC emissions

The HC emissions reduction is observed throughout the power range in case of ethanol blends as compared to gasoline as it is evident from Figure 5. Since the entry of the fuel vapour to the crevices, flame quenching and absorption by the oil layer would be more or less similar for all the ethanol blends. Thisshows a decrease in HC emissions with gasohol.

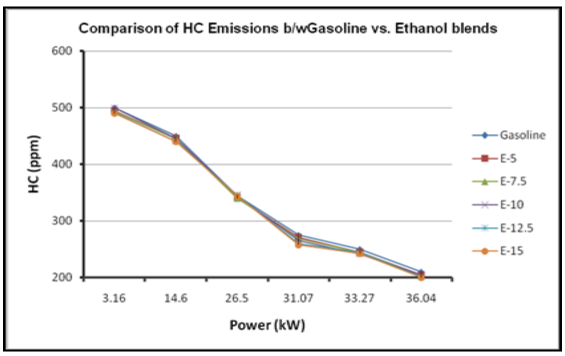

Figure-5: HC v/s Power for Gasoline Ethanol Blends

NO_x emission

There is no considerable difference w. r. t. NO_x emission, when the engine was run on gasoline and ethanol blends as clear from Figure 6. In some cases there is a little decrease in NOx emissions with the ethanol blends. NOx emissions with E10 and above were observed to be lower as compared to gasoline with the engine equivalence ratio maintained in the range of 0.85-0.95 by the engine lambda sensor. It is found that as the blend percentage is increased the maximum NOx emissions take place at higher value of equivalence ratio i.e. at much richer mixtures than stochiometric because of the inherent oxygen content in ethanol.

Hence for the ethanol gasoline blends the tendency of nitrogen to oxidize to NO and NO_2 will be lesser as compared to gasoline. Also ethanol flame's lower luminosity reduces the heat loss by radiation and leads to lower NOx emission from the engine.

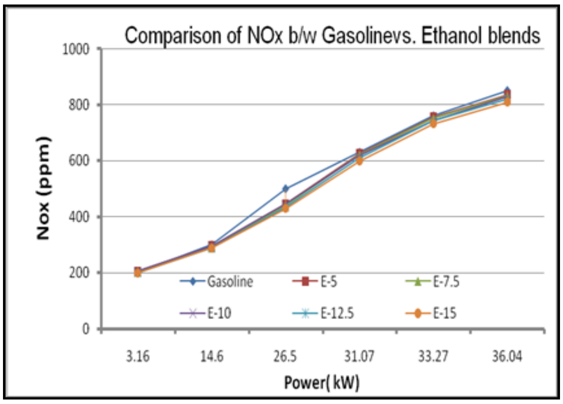

Figure 6: NOx v/s Power for Gasoline Ethanol Blends

Conclusions

The following conclusions can be summarized from the above analysis.

- The inherent oxygen content of ethanol is the chief contributor to the increased power output and thermal efficiency with the ethanol gasoline blends. Additionally a higher latent heat of vaporisation and a higher flame velocity also contribute to the power based performance.
- Higher boiling point of ethanol and a wider range of flammability limit have led to the development of cold start technologies as the most important technologies with the ethanol usage.
- CO, HC and NOx emissions with Bio-Gasoline are found to be reduced owing to more complete combustion of the air fuel charge under lean burning conditions created by the ethanol molecule. Higher Peak cycle pressures and greater exhaust gas temperatures also can't be ignored if an ethanol fuel performance based evaluation is to be done.
- The low energy content of ethanol is its most limiting factor in its acceptance for fuel economy and performance reasons
- The unmodified SI Engine performance and emission based benefits are limited by the aldehyde emissions, swelling of the fuel hose rubber components, gaskets

and the galvanic corrosion, gum deposits associated with the fuel tanks are some of the issues associated with the Ethanol fuel and thus can't be overlooked.

- Finally if in future India wishes to extract the emission based benefits of higher ethanol gasoline blends ,may be E85, then specific engine based modifications will have to be incorporated to reap the benefits of using a clean air fuel.

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