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Effect of ethanol-gasoline blend on spark ignition engine: A mini review

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ABSTRACT

An increase in the energy demand has accompanied the increasing prevalence of the population. Ethanol is an excellent alternative to conventional fuel. At the same time, globally, bio-ethanol production is gradually increasing day by day. As an oxygen-containing compound, it generates low PM emissions and significantly reduces greenhouse gas emissions. Ethanol increases the oxygen content of the fuel and burns it completely. This review focused on the comparative analysis of ethanol properties with other alcohol and conventional fuel specifications. The effect of ethanol on spark ignition engine characteristics is also discussed in detail. Ethanol has now become the most abundant and broadly used bio-fuel today. However, few obstacles are there in using ethanol in diesel engines. High octane number is the main reason why ethanol can be best for SI engines.

1. Introduction

The use of alcohol as a fuel for an internal combustion engine is not a new concept. Ethanol-diesel blends, which are used in unmodified diesel and gasoline engines, reported a similar or even improved brake thermal efficiency when operated with mixed fuels compared to conventional ones. A comparison of ethanol with other alternative fuels used in the transportation sector is mentioned in Table 1.

Various studies found that alcohol together with diesel fuel gave satisfactory results in CI engines. The blending of ethanol with diesel reduces the fuel viscosity and lubricity [1], results, increase in the probability of leakage. Therefore, it can be a cause of decrement in power output. Another reason for the decrement in power output is the low energy content of ethanol compared to conventional fuel. Hence, to produce the same power, more alcohol content is required by mass and volume. The solubility of E-diesel is another limitation of the blend. Two significant factors lead to the separation of ethanol–diesel blend i.e., temperature and moisture content. Hence, a higher proportion of ethanol is not allowed, as it could not mix [2]. The separation can be prevented by using an emulsifier or adding a co-solvent between ethanol and diesel [3].

In addition to the lower calorific value, very high latent heat of vaporization, there is a serious health hazard associated with methanol, limiting the use of methanol over ethanol as an automotive fuel. Methanol is a highly toxic substance used as an alternative fuel, industrial solvent, and automotive antifreeze. Moreover, it is hazardous in the case of human consumption since it leads to severe visual disturbance. Methanol is more toxic than ethanol. The key reason behind this when methanol is converted into aldehyde, it leaves the by-product of formaldehyde, which is toxic. Robert and Nauss examined methanol toxicity in humans [4], primarily due to automotive methanol vapor. They reported that the consequences of acute exposures to methanol lead to uncompensated metabolic acidosis with superimposed toxicity to the visual system. In this literature review, the use of ethanol as a binary fuel in gasoline engines is discussed in detail, along with its effect on engine performance, emissions, and combustion characteristics.

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Table 1
Comparison of ethanol and alternative fuel in the transportation sector.

Fuel	Density (g/cm^3)	LHV (MJ/kg)	HHV (MJ/kg)	Cost (Rs/Liter)
Gasoline	0.720–0.800	43.3	46.4	85.70
Diesel	0.810–0.860	42.6	45.6	75.70
Ethanol	0.785	26.9	29.7	54.27
Methanol	0.7866	20.1	22.7	38.00
CNG	0.180	46–49	–	44.23 Rs/kg
LNG	0.420	25	–	
H2	0.09*10–3	120	142	876 Rs/kg
Biodiesel	0.870	36.5–38	39–41	

2. Ethanol in SI engine

Several techniques/methods are widely available to produce ethanol. The feedstock which is used to produce ethanol is widely available such as sugar cane [5], olive tree felling/wheat straw/vine shoots [6], cellulosic biomass [7], and synthesis gas [8]. Ethanol is one of the promising partially oxidized fuels since its molecule contains oxygen atoms [5,9]. Greenhouse gas emissions led to climate change played a vital role in accelerating the technological development of alcohol production via biomass and its usage in IC engines [10,11]. In a recent development, alcohol has been widely utilized as a fuel for SI engines, methanol under high compression ratio [12], ethanol as a port fuel in the dual fueling mode [13], and hybrid engine gasoline/bio-butanol [14]. To study the combustion, performance and emissions of SI engine [15] running on pure ethanol, methanol, and unleaded gasoline at three different compression ratios (8:1, 8.5:1, and 9:1), authors have performed an experimental investigation on single-cylinder, 4-stroke engine. In the case of pure ethanol and methanol, the performance parameters of the engine, i.e., Brake Mean Effective Pressure (BMEP), Brake Thermal Efficiency (BTE), and volumetric efficiency, showed greater values compared with unleaded gasoline at all three compression ratios. However, emissions like NO_x, HC and CO declined in case of alcohols compared with gasoline. In-cylinder pressure obtained from three fuels showed that maximum value was found with alcohol fuel (refer Fig. 1) compared with unleaded gasoline, also peak pressure was found earlier or near the TDC.

Al-Hasan [16] investigated the performance and emissions of SI engines fueled by gasoline and ethanol blends. The findings of this experiment revealed that 20 % ethanol leads to increase brake power, BTE, volumetric efficiency, and reduce harmful emissions, CO & HC. The use of EGR and ignition timing showed effective means to control SI engine load, while the engine is utilizing methanol as fuel at fixed speed within the load range of BMEP of 0.36 to 0.96 MPa [17]. However, at increasing EGR rate, load on the engine was lowered together with advanced ignition timing to avoid any adverse effect on the performance of the engine. Methanol possesses greater oxygen (50 %) compared with ethanol; therefore, it produces faster flame speed at a lower air/fuel ratio.

In the recent development, it was leading automobile manufacturers, like Volkswagen and Toyota using dual injection strategy to supply fuel through direct in-cylinder and port fuel injection of gasoline and ethanol, respectively. Blending ethanol with gasoline [18] in the SI engine showed reduced NO_x, CO, CO_2, and HC emissions. In another work effect of 10 %ethanol-gasoline & 20 % ethanol-gasoline blends and the effect of varying compression

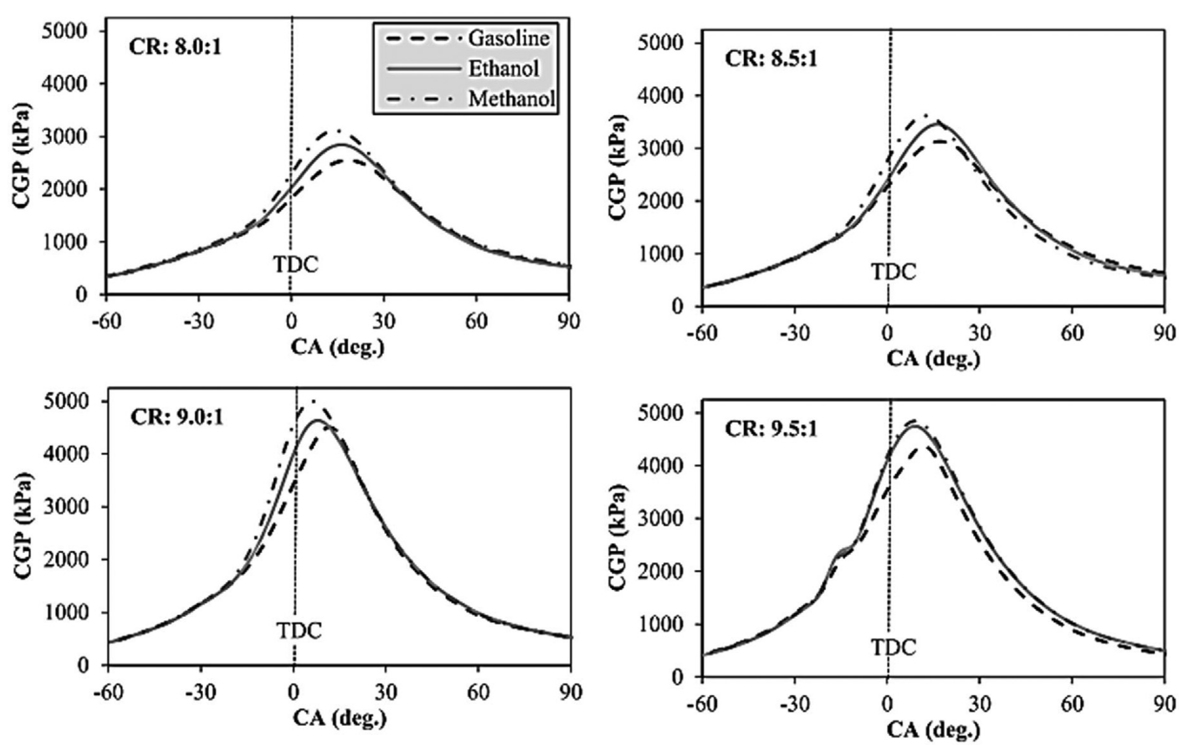

Fig. 1. Variation in CGP for three fuels [15].

ratios (5 CRs) were studied to analyze performance and emissions of pure ethanol SI engine [19]. Authors have found BTE and BMEP increases with an increase in CRs for both gasoline and gasoline-ethanol blends. However, after reaching the maximum point, the trends become reverse. In addition, ethanol-gasoline blends provided lower emissions of HC, CO and NOx compared to gasoline. In another interesting investigation, it was found that ethanol (25 % v/v) gasoline blend lead to effective control the particulate emissions [20], transmission electron microscope revealed that primary particle means diameter is also smaller compared with gasoline. It has been established by Honda [21] that modifying the design of the intake port & combustion chamber of gasoline fueled SI engine (1.3 L and 2-plug) led to create significant improvement in brake specific fuel consumption, knocking tendency, engine torque; also, it showed a decrease in emissions. Altin et al. [22] performed -a simulation study on the SI engine using a quasi—dimensional two-zone thermodynamic model to predict the performance and combustion of the engine. As depicted in Fig. 2, it is found that diagonally located dual-plugs (SpL@d) compared with two other two configurations, centrally located (SpL@c) and side located plug (SpL@s), showed maximum in-cylinder pressure; the reason could be due to ignition of fuel at two different points led to reduce flam front travel distance and combustion duration (fast burning). However, the shortest combustion duration was found with a centrally located spark plug.

At constant speed and 25 % and 50 % engine loads, the effect of alternate fuel ethanol and acetylene was studied [23] to analyze the performance and emission of the 4-cylinder, 4-stroke SI engine. They have found acetylene could be one of the promising alternate fuels, which can reduce harmful emissions (HC and NO) without sacrificing performance. Researchers have established it after performing significant work to demonstrate the application of ethanol and gasoline blends in the SI engine to improve the application of ethanol and gasoline blends in the SI engine to improve performance and reduce emissions.

In a recent development, the application of *n*-butanol as fuel is facing a challenge due to the high production cost. However, the production of butanol through biomass uses Acetone-butanol-ethanol (ABE) fermentation process wherein ABE is one of the intermediate products. Nowadays, several researchers are showing interest in investigating its use in SI engines as an alternative fuel. Moreover, experimental investigations revealed that blends of diesel and ABE [24–26] reduce harmful emissions and improves the BTE of diesel engines. To study the performance and emission of SI engine, it can be used in different volumetric proportions, i.e., A:B:E 3:6:1, 6:3:1, and 5:14:1 [27], ABE was produced by fermentation of bagasse and wheat straw. ABE compared to gasoline showed a positive impact on BTE, whereas a higher amount of *n*-butanol results in an increase in HC and CO emissions. For all test fuels, due to the low calorific value of constituent of ABE fuel compared to gasoline, BSFC was higher than gasoline. ABE fuel [28] was supplied through the port and directly injected gasoline studied at various lambda values to evaluate the performance of the SI engine. They found that 50 % ABE port fuel injection with gasoline fuel could be alternate fuel for SI engines. A recent study reported a comparative evaluation of different injection modes (direct and port) of gasoline and ABE to examine combustion and emissions of SI engines [29]. Results demonstrate the potential benefits in terms of lower emissions and higher efficiency of dual injection SI engine, during port injection of gasoline and direct injection of ABE or direct injection of gasoline and port injection of ABE as well as both port and direct injection of gasoline. Subsequently, in another work, they have investigated the performance of SI engine while utilizing dual fueling strategies, gasoline port injection and ABE direct injection, to examine the effect of varying ratio of ABE, excess air ratio (λ) and injection timing of ABE [30]. Results of this study also revealed that emissions and IMEP showed improvement over gasoline fueled engine, the optimum values have been found for ABE direct injection timing and direct injection ratio were 300 °CA BTDC and 0.6 respectively.

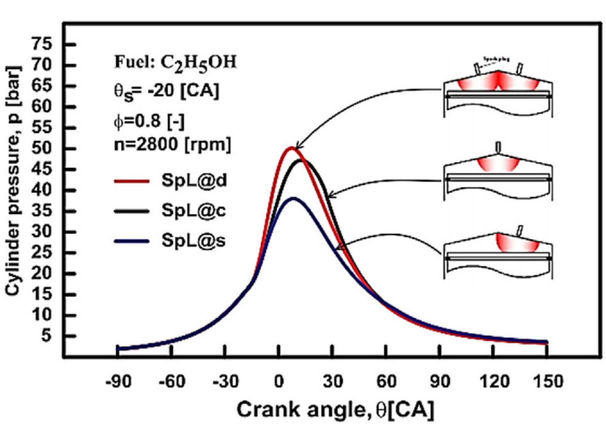

Fig. 2. Effect of spark plug configuration on cylinder pressure [22].

In another study, authors [31] have studied the effect of ABE blends with gasoline, spark timing, and lambda on performance and emissions of 4-cylinder high-speed SI engine. Three different ratios of ABE and gasoline (ABE10, ABE20, and ABE30) were used in this study; fuel was supplied by injecting it with the help of a low-pressure port fuel injector. Advance spark timing together with port injection of ABE-gasoline blend led to increasing BTE & output power. However, under lean mixture conditions, it deteriorates BSFC compared with gasoline. NO emission showed a strong dependency on spark time compared with CO & HC emission.

A single-cylinder SI engine was modified to operate on gasoline and ethanol, and gasoline was injected by using a peak and hold type multi-hole Gasoline Direct Injection (GDI) injector and two Port Fuel Injectors (PFI) were used for injecting ethanol into the intake port [32]. They studied the effect of dual fuelling, i.e., ethanol (port injection) and gasoline (direct injection), on combustion and emissions of an engine at two different compression ratios (9.5 and 13.3). Results revealed that knock frequency and PM were reduced significantly by retarding ethanol injection. Table 2 summarizes the ethanol diesel studies through fumigation and blending. Few more work has been done on fuel losses and fumigation of gasoline and diesel engine.

3. Conclusion

- By comparing the pros and cons of other alternative fuels, it was found that not any of the alternative fuels has a complete set of advantages. Comparatively, ethanol has a good foundation and outlook presently. It is compatible with existing engines with moderate or no modification.
- Since the ethanol/gasoline blended fuels are producing lower carbon numbers compared to pure gasoline hence, CO_2 emissions were reduced with their blend. In terms of fuel consumption, the lower heating value of ethanol compared to gasoline, a high amount of mixture is required to be injected with ethanol/-gasoline blends. Although during the cold combustion, the engine is operated with rich A-F ratios, however, being oxygenated compound, ethanol /gasoline blends is capable of producing leaning effect which further enhancing the fuel consumption.

Table 2
Summary of ethanol–Gasoline studies through blending and fumigation.

Engine type/Simulation model	Ethanol proportion	Reference fuel	Performance	Combustion	Emissions	Ref.
Single Cylinder, gasoline direct injection	Varying amount while keeping lambda 1	Gasoline	Indicated efficiency ▲	Knock frequency ▼ by retarding ethanol injection timing	HC, NOx▲ CO▼ at CR 9.5particulate mass (PM) and particulate number (PN) ▼ at CR 13.3	[32]
SI Engine, 4-cylinder, 4-stroke, water cooled (1.8 L)	Ethanol, acetylene, gasoline	Gasoline	BTE ▲ with acetylene fuel	flame speed▲ with acetylene fuel and knock resistance ▼	HC, NO and CO▼ with acetylene fuel	[23]
Single cylinder SI engine	Acetone-butanol-ethanol (ABE)	Gasoline	BTE ▲ BSFC ▲	——	HC, CO ▲	[27]
Single cylinder SI engine (Pure Ethanol)	10 % and 20 %	Gasoline	BTE ▲ BSFC ▲ Volumetric efficiency ▲	BMEP ▲	HC, CO and NOx▼	[19]
Single cylinder SI engine	Acetone-butanol-ethanol (ABE)	Gasoline	BTE▲	Pmax, IMEP,	HC and PN▼	[28]
4-cylinder, dual injection SI engine	Gasoline and ABE	Gasoline	BTE▲	Torque ▲ CoVIMEP ▼	NOx▼ HC ▼ CO▼	[29]
			While engine is fueled by port injection of gasoline and direct injection of ABE			
4-cylinder, combined injection SI engine	Gasoline and ABE	Gasoline		IMEP ▲	NOx▼ HC ▼ CO▼	[30]
4-stroke, 4-cylinder, SI engine	Gasoline and ethanol blend	Gasoline	BP, BTE, Torque, Volumetric efficiency BSFC ▼		HC ▼ CO▼ CO2 ▲	[16]
SI engine	Gasoline and ethanol blend	Gasoline		Torque ▲	HC ▼ CO▼ CO2 ▲	[5]
Single cylinder, 4-stroke, SI engine	Pure ethanol, methanol and gasoline	Gasoline	BTE, BSFC, volumetric efficiency▲	BMEP▲	HC ▼ CO▼	[15]

CRediT authorship contribution statement

Ram Kunwer: Methodology, Validation, Supervision, Project administration. **Subrahmanya Ranjit Pasupuleti:** Investigation, Resources, Writing – original draft, Writing – review & editing. **Swapnil Sureshchandra Bhurat:** Conceptualization, Software, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Santhosh Kumar Gugulothu:** Writing – original draft, Writing – review & editing. **Devandra Singh:** Writing – original draft, Writing – review & editing.

Data availability

No data was used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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