J. Integr. Sci. Technol. 2022, 10(2), 87-99 Review

Journal of Integrated
SCIENCE & TECHNOLOGY

Effects of blending bioethanol with gasoline on spark–ignition engine – A review

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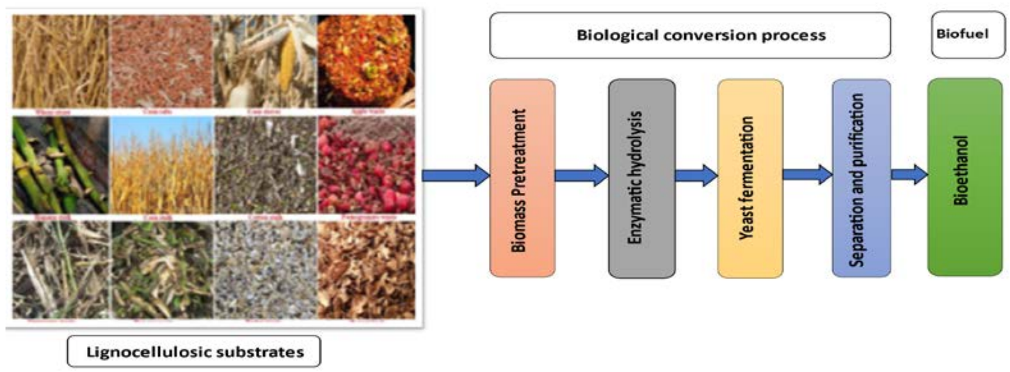
Received on: 22-May-2022, Accepted and Published on: 07-July-2022

ABSTRACT



Due to strict government regulations and fossil fuel depletion, it was necessary to look for alternatives to traditional fuel sources. Energy demand is increasing day by day due to improved transportation and population growth. Biofuel is an alternative fuel derived from various types of biomasses. Biofuels are receiving scientific and public attention. This can be caused by factors such as the need to strengthen energy security, rising oil prices, and concerns about greenhouse gas (GHG) emissions from fossil fuels. Biofuels are especially attractive for developing countries because they can arouse economic development in rural areas and alleviate poverty by creating employment opportunities & higher incomes in the agriculture sector. The blending of bioethanol leads to improve physicochemical properties which are responsible to improve the SI engine. SI engine operation improves with the help of Physico-chemical properties of bioethanol. The present review illustrates the production of bioethanol from different types of biomasses, their physicochemical properties, and their impact on the engine: combustion characteristics, engine performance, emissions, the effect of bioethanol gasoline blending & operating conditions for NOx emission in SI engine.

Keywords: Bioethanol, biomass, gasoline, diesel, spark-ignition engine

INTRODUCTION

A major global problem is the energy crisis, due to rapid population growth, industrialization, and improved transportation energy demand is constantly increasing.[1] Fossil fuels are standard sources of energy including nuclear and hydropower, coal, natural gas, and diesel. Based on fossil fuels about 70% of energy production is expected to continue until 2035.[2,3] Stocks of fossil fuels are available in limited quantities and non-renewable which is one of the great challenges of the 21st century. As the demand oversteps the supply the world is marching towards the oil crisis.[4] As petrol consumption is higher its price goes up, and day by day it moves to extinct.[5] The price and demand of crude oil increasing day by day throughout the world thence it is necessary to search for alternative fuels. In the sector of automotive, compression and spark ignition are major sources of engine power despite the oncoming technology of electric vehicles. Therefore, the demand for fossil fuels and other consumables was continuously needed. The problem has been solved by providing additional renewable energy sources such as biofuels, wind power, solar power, and fuel cells. Biofuel is becoming a common alternative and also it can be used in various industries as a 10% blending due to various properties such as oxygenation, renewable energy, and low pollution. Thakur[6,7] and Thangvelu et al.[8] reported a comprehensive study on bioethanol as a substitute fuel for the SI engine. Recently a 20% blending of bioethanol in gasoline has been announced by the Indian Government till the year 2025. Bombardier Q400 aircraft was tested successfully with 25% jet fuel by Spice Jet with 20 passengers. In recent decades the demand for additional bioethanol and its supply has almost tripled.[9] To achieve its energy demand India alone will need 1000 crore liters of bioethanol. Therefore, it

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Cite as: *J. Integr. Sci. Technol., 2022, 10(2), 87-99.*

 ISSN: 2321-4635 http://pubs.iscience.in/jist

is necessary to establish additional sources of bioethanol production. National policies of India and various biofuel plants were in reported literature.[10] To meet bioethanol future requirements, the Indian government needs to enhance, and improve bioethanol analysis by changing its funding & establishing new bioethanol sources, enhance and specific policies. Bioethanol can be produced by using cellulosic feed such as corn, sugarcane, vegetable waste, sugary beans, barley, molasses, sweet sorghum, and agricultural waste such as discarded wood, livestock, and grass.[11] Figure 1 shows different feedstocks for the production of bioethanol.

To remove lignin and stabilize hemicellulose different pretreatment methods like acidic treatment, thermal treatment, and alkaline treatment.[12–19] When combined with diesel fuel it reduces the attractiveness of bioethanol-diesel compounds also it has some certain petroleum properties such as low lubrication rates, energy density, temperature, cetane number, and phase separation. At low temperatures blending of bioethanol forms an important aspect of the use of bioethanol diesel in the ignition engine.[20] Strong cetane enhancers & lubricant additives have robust technological changes and also improve the chemical properties of the fuel.[21] Hansen et al. (2005) reported that in presence of water the bioethanol diesel blend solubility was affected by temperature and aromatic aromatic content of diesel. Due to the polar nature of bioethanol, it induces dipoles in aromatic molecules and interacts with other hydrocarbons. Therefore, to some extent, the aromatic content acts as a bridging agent. Kumar et al[22] reported that a reduction in aromatic diesel content reduces ethanol miscibility in diesel. The blend properties of bioethanol diesel facilitate the combustion process and improve emissions of particulate matter, carbon dioxide, carbon monoxide, etc. To reduce particulate emissions reduction of greenhouse gases and economic savings in regional air quality oxygen-based fuels were promoted.[23,24]

As shown in table 1 different review shows exhaust emission characteristics and performance on SI engine. Few of these provide a detailed analysis of compression ratios, engine load on combustion behaviour, NOx emissions, and cold start effects when using bioethanol as a gasoline alternative.

At different engine operating conditions, the bioethanol blending decreases particulate emission which controls NOx conditions. Reductant stimulating NOx adsorbers may be provided by high THC release.[25,26] When bioethanol is produced from `different sources of biomass[27] it decreases emissions of greenhouse gases and other environmental advantages related to ethanol diesel fuel consist of advanced biological decomposition.

Further research and analysis have been found regarding the substitution of diesel fuel components and blending of diesel/ gasoline and bioethanol in a spark-ignition engine which has been successful as a commercial point of view. The purpose of this study is to investigate the physicochemical properties of the bioethanol blends and its effect on engine performance combustion characteristics, and emission analysis.

Bio-ethanol Production

In the history of human civilization, alcohol has always been present. It came to be regarded as the fuel of automobiles at the end of the 19th century. Bioethanol production is done in two main ways of industrial production. (i) The production of bioethanol from renewable bio-organic materials by fermentation and distillation process form new methodologies namely pretreatment and hydrolysis[28] and (ii) the reaction of ethane with steam.[29,30] The global bioethanol production by different feedstock from 2007 to 2019 shown in figure 2.

The main categories of raw material were classified in the review of Thangavelu et al. such as Agricultural residues: sweet sorghum bagasse, wheat straw, rice straw, rape straw, sugarcane and horticulture waste. Algae biomass: macroalgae, and red seaweed gracilaria sp., recently for the production of bioethanol it is used. Woody biomass: (C & D) waste i.e., construction and demolition, yellow poplar. The authors reported that for high yield of bioethanol production (C & D) waste is more suitable worldwide. In short, at the commercial level, the authors claim that red seawood gracilaria sp, microalgae, and Chlamydomonas reinhardtii provide a high production of bioethanol (greater than 20%). Edible crops i.e. corn, cassava, sorghum, sugarcane are used for the first generation of production of bioethanol.

Table 1 : List of different review articles from (2010-2021) based upon exhaust emission characteristics and performance

Focused on bioethanol	Engine performance on SI engine	Engine performance on CI engine	Combustion characteristics of SI engines	Exhaust emission of SI engine	References
×	×	×	×	×	S.N. Naik et al
×	✓	×	×	✓	M.Kirana et al
✓	✓	×	✓	✓	B.M. Masum et al
✓	✓	×	✓	✓	Yusoff et al
×	×	✓	×	×	Shahir et al
×	×	✓	×	×	Rajesh Kumar et al
✓	✓	×	×	×	Thakur et al
×	✓	✓	×	✓	Yusri et al
×	×	✓	×	×	Geng et al
✓	×	✓	×	×	S. Verma et al
✓	✓	×	×	×	P.Chansauria et al
×	✓	×	✓	✓	Awad et al
×	✓	×	×	✓	Awad et al
×	✓	✓	×	×	Erdiwansyah et al
✓	✓	×	✓	✓	Veza et al
✓	×	×	×	✓	Iodice et al
✓	✓	×	×	✓	Bharath et al

✓ : included × : not included

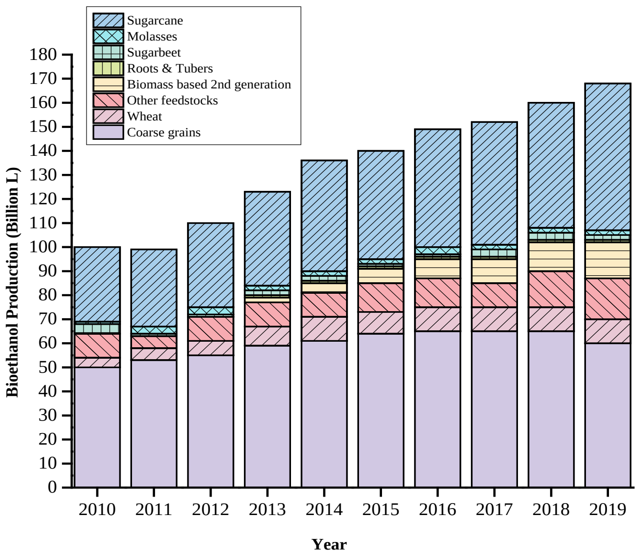

Figure 2: Global bioethanol production from 2007 to 2019 [31]

Donke et al.[37] have measured the social and environmental impacts of bioethanol production from sugarcane, cereals, and corn. They highlighted the huge impact of sugarcane cultivation on social and economic levels, and human toxicity and the impact on climate have also been highlighted.

Velazquez- Marti et al[32] reported that bioethanol production from sugarcane decreases costs and shows a great opportunity for agriculture development, they have also suggested a mathematical model to improve bioethanol production and its quality. Berlowska et al [33] proposed that by the processing of sugar beets in sugar factories the waste which is generated can be further used for bioethanol production.

Nuanpeng et al[34] reported that at high-temperature bioethanol was produced by using Saccharomyces cerevisiae DBKKU Y-53 from sweet sorghum juice (SSJ). Yu et al reported bioethanol production with the help of Kluyuveromyces marxianus yeast from agricultural waste.

Ariyajaroenwong et al[35] Saccharomyces cerevisiae NP01 were used for the production of bioethanol from sweet sorghum stalks, and sweet sorghum juice which showed for the repeated batch of bioethanol for the optimum size of sorghum stalks. When using immobilization systems, reduces production costs because the program offers benefits in addition to free cell proliferation i.e., high levels of yeast cells, high levels of fermentation, easy cell recycling, and a reduction in inhibitory production.

A new substrate i.e. Landoltia punctata was reported by Chen et al for bioethanol production.[36] To improve bioethanol production and for releasing more sugar Pectinase pretreatment method was used by using duckweed as a feedstock.

For the production of second-generation bioethanol, the feedstock used is the source of non-edible forestry and source of agriculture. Starchy and lignocellulosic materials can be converted into anhydrous bioethanol. The cost of the enzyme which hydrolyses cellulose is a limiting factor. Pre-treatment, hydrolysis, fermentation, and distillation are the various process for the production of bioethanol.[37–39]

Rajendran et al[40] reported that bioethanol production generated from first and second-generation increases the production rate by 4% and reduces energy consumption by 2.5% with the help of new materials (filaments fungi). Conolly et al[44] have different modes of fuel production that combine bioethanol and methanol according to the conversion process used and the transport requirements that are met. Hence according to this, the best solution contains liquid fuels such as dimethyl ether or methanol. The technologies which need to be improved are biomass gasification and electrolysis.

Carbohydrates/ polysaccharides, lipids, proteins, and thin cellulosic walls are the third-generation feedstock for bioethanol production. According to Baeyens et al,[39] the left-over cake containing starch and cellulose can be converted into bioethanol. Furthermore, CO_2 fermentation was produced in the bioethanol process which can be captured and used. Improving bioethanol production is an ongoing concern for experts in the field. For the synthesis of bioethanol from syngas Lopez et al have suggested a Rhodium-based MCM-41 catalyst. According to their study, Rhodium-based MCM-41 shows a higher effect of water on the selectivity of the product as compared to Rhodium-based SiO_2.

According to Cesaro A et al[41] bioethanol and biogas were produced by fermentation and anaerobic digestion method respectively further it produces heat and electricity which improves overall energy balance. The strength and weakness of integrated treatments getting much more attention by using a combination of both bioethanol and biogas. Elnashaie et al[46] reported the concept of biodiversity integration as a complex field that combines the process of conversion of biomass and materials to produce fuel.

In this section different raw materials and technologies for bioethanol production were given in detail. Special attention is given to the various remnants of the food industry and lignocellulosic biomass. Algae has been considered a renewable third-generation resource for the future of road mobility. To increase productivity and reduce the final product cost different types of fungi can be used.

THE POLICY OF BIOFUEL IN INDIA

In 1977, to investigate the issue regarding the blending of bioethanol in gasoline six technical committees and four study groups were set up. When the Department of Petroleum and Natural Gas carried out exploration work in three areas of Maharashtra and Uttar Pradesh to study the potential of bioethanol mixing in gasoline and diesel was highlighted only in the year 2000. In 2001 in Maharashtra, these projects were launched in Miraj and Manmad and Bareilly in Uttar Pradesh. Bioethanol-blended gasoline was sold through 300 retail outlets under these plans. Six other such projects were implemented in Andhra Pradesh, Punjab and Uttar Pradesh in 2002. Simultaneously, the effect of bioethanol-blended gasoline on automobiles was carried out by Research and Development. India has achieved the target 10% bioethanol blending in petrol five months before deadline. The rise in bioethanol blending in petrol from 2% in 2014 to 10% reduced carbon emission by 27 lakh tones & also brought Rs. 40,000 crores of income to farmers.[42]

The worldwide creation of fuel bioethanol contacted 110 billion litres in 2019 appearance a typical development of 4% year out of each year during the last 10 years. The United States of America (USA) and Brazil make a commitment for ninety billion litres (84% of worldwide rate) saw via European Union (ECU), China, India, Canada and Thailand. In order to increase the availability of bioethanol for use in transportation, various countries around the world have taken many initiatives Table 2. Brazil has mandated that the bio-alcohol content of gasoline sold in the country must be between 18% and 27.5%, currently blending used is 27%. Simultaneously, the utilization of 100 percent water-based bioethanol by flex-fuel vehicles in Brazil expanded the normal bioethanol blending in transport to 46% in 2019.

Table 2: Bioethanol blending in various countries [42]

Country	Policy for bioethanol blends	Program	Executed by	Vehicle type
Brazil	According to Brazil's policy the blending of 18-27.5% Currently, this ratio is 27%.	National Biofuel Policy (December 2017)	MME	Mostly flexible. Motorcycles and other two-wheelers using E27
China	The Chinese government reported the objective of 10% bioethanol blending in sept. 2017	Fuel quality standards	National energy administration	Primarily normal
United States	The Clean Air Act mandates that the EPA yearly set the volume requirements for the RFS.	RFS program	EPA	Flex for only E30 or E85
European Union (EU)	By 2020, the EU wants 10% of all car fuel in its member states to come from non-renewable sources, such as biofuels.	RED	European commission	Flex and normal
Thailand	To increase the share of optional and renewable energy source bioethanol from 7% use in 2015 to 25% in 2036.	ADEP	Ministry of Energy	Primarily normal

MME: Ministry of mines and energy; **RED:** Renewable energy directive; **RFS:** Renewable fuel standards; **EPA:** Environmental protection agency; **ADEP:** The Alternative Energy Development Plan

Physico-Chemical Properties of Fuels

To test different mixtures and whether they are suitable for use in an engine, physicochemical properties need to be analysed. Viscosity can affect the operation of fuel injection. The viscosity of the fuel increases when the ambient temperature decreases. Deterioration of engine is the most important factor which should be taken into consideration. Thus, the high viscosity of the fuel causes poor fuel evaporation and atomization of the large inlet of the fuel cylinder and larger droplets when starting cold in the lower ambient. Clenci et al[43] reported that a high viscosity reduces fuel flow rates which resulted in pump distortion and inadequate fueling. The final effects may be seen as severe combustion increased oil increases and high emissions.

A key indicator of the combustion and autoignition characteristics that are used in the CI engine is the cetane number (CN). Clenci et al [41] proposed that the cold start ability of an engine influence also decreases engine cracking time.

The fuel ignites at minimum temperature (101.3 kPa) is known as flashpoint. The FP value is dependent upon the volatility of the fuel, if the volatility is higher FP value will be lower. Hence, for appropriate fuel handling and safety low FP values are required.

At low ambient temperature, the CI engine operation is affected by three fuel properties.

- The temperature at which strong particles arise within the gas which results in a clear liquid product that forms a cloud is the Cloud factor (CP)
- The lowest temperature at which for extended periods of time a certain amount of fuel will flow through a standard device is Cold Filter Plugging Point (CFPP).
- The lowest temperature at which fuel flow stops is the pour point (PP).

The fuel type must be suggested where the engine is to be operated for a given CI engine with the help of climatic and seasonal features.

The heating value of fuel was described by energetic content. Recently the use of blended fuels for dual fuel CI and SI engines is reported.[44–46] It is very important to develop techniques and models to evaluate the LHV and HHV of the used mixture.

A major factor for fuel is the water content. At negative temperatures, water can plug the fuel filters which resulted to fuel blockage also this water increases corrosivity which accelerates and promotes oxidation and microbial growth respectively.

Physicochemical Properties of Bioethanol

Bioethanol is oxygenated liquid hydrocarbon fuel. C Bae et al[9] reported the hydrophilic and dipole moment nature of bioethanol from the hydroxyl moiety. When this bioethanol is blended with gasoline it is becoming hydrophilic and it behaves near an azeotrope because blending possesses the polarization which influences the inter-molecular interactions through dipole moment. The simple distillation technique cannot be used for a mixture of two or more liquids. The vapor has the same proportions as the unboiled mixture when the azeotrope is boiled. The physical properties of bioethanol is shown in table 3.[47] In SI engines, damage can occur because spontaneous combustion occurs before and after the production of sparks resulting in engine knocking. The alcohol fuels show a higher-octane number (ON) for achieving a higher indicated efficiency

Choongsik et al[10] reported interaction between ON and the high-pressure rating indicated an increase ON which is required for each CR by four to six units. The volatility of alcohol is lower than diesel fuel because alcohol represents a solution to the development of instability due to their kinematic viscosity and low concentrations. Bioethanol can have an adverse effect on the size of the oil droplets mixed negatively due to their low concentrations and kinematic viscosity. Alcohol fuels have a relatively high evaporation temperature; So, better results should be expected, so that it could lead to an increase in volumetric efficiency.

Table 3: Physical properties of bioethanol

Property	Bioethanol
Formula	CH_3CH_2OH
Molar mass [kg/kmol]	46
Weight of Oxygen (wt %)	34.8
Density [kg/m^3]	785 [48]
Lower heating value (LHV) [MJ/kg]	27 [49]
RON (research octane number)	110
CN (cetane number)	11 [50,51]
Air–fuel ratio (Stoichiometric), A/F [kg/kg]	9.0
Latent heat of vaporization [kJ/kg]	910
Boiling point [□C]	(78–78.3)
Specific heat [kJ/kg K]	2.4
Vapor pressure [KPa]	21 [52]
Kinematic viscosity[mm^2/s]	1.3
Flash point [□C]	22 [53]; 24 [49]
Auto-ignition temperature [□C]	425

Influence of different blends on CI engine

The influence of different blends on CI engine operation was discussed below.

Combustion characteristics

Combustion can define the dynamic, ecological performance, nature of an IC engine, and also it is the most complex thing. Table 4 summarizes the various properties of combustion characteristics: the heat release (RoHR), the rate of heat reignition delay (ID), duration of combustion (DoC), the cylinder temperature and pressure (Tcyl) and (pcyl) respectively.

Engine Performance

The study of various parameters of engine performance are summarized in table 5 parameters included BP, EGT, IMEP, BSFC.

Emissions

Table 6 summarizes the different emissions such as NOx, smoke, UHC, PM, CO. Also, the effect of bioethanol in gasoline blends on NOx emission and operating conditions provided in table 7.

Conclusions

The present paper explains a review of bioethanol blending with diesel and gasoline and its effect on the performance of spark engines. Also, the study of the effect of bioethanol blends with the help of different parameters such as combustion characteristics, engine performance, and emissions was studied and shown in table 4, table 5 and table 6 respectively. The crucial sector of economy is automotive industry, it is creating jobs and making a positive contribution to fair trade which is essential to world prosperity. Today however, road transport is the subject of much political debate, as it deals with a significant portion of GHGs (greenhouse gases) and pollutants released into the atmosphere. Therefore, the negative impact on the environment are highly considered for any measures. Among these approaches, alternative biofuels play an important role and will continue to contribute to the future of road transport. The key conclusions drawn from the present work can be summarized as follows. The importance of alternative biofuels is the need to pursue energy sustainability by increasing the use of renewable energy sources, thereby reducing the potential for fossil fuels.

The effect of bioethanol-diesel blend fuels:

- Regarding combustion characteristics:

In all studies combustion duration decreases; as blending increases rate of heat release increases; the ignition delay and cylinder pressure increase with an increase in bioethanol-diesel blends.

- Regarding engine performance:

In all studies BTE, BP, BSFC is higher; minor variations were observed for exhaust gas temperatures; for more than 35% bioethanol in the fuel blends indicated mean effective pressure has minor variations.

- Regarding emissions:

NOx, smoke and PM emissions appear to be lower and HC and CO emissions depend on fuel mix type and operating conditions. The effect of the bioethanol-gasoline blend is on the various parameters of combustion characteristics is as follows

a) The addition of bioethanol into gasoline leads to smoother operation it improves combustion and decreases the duration of combustion.
b) The bioethanol blending resulted to an increase in the pressure of cylinder and also increase rate of heat release.
c) Combustion stability for each mixture has been verified as COV values.
d) A higher-octane rating of the fuel has a significant effect on gasoline engines, the more the octane rating of the fuel the better gasoline engines.

Table 4: Combustion characteristics

Different blending samples	(DoC)	(RoHR)	ID	Pcyl	Tcyl	Ref
E5%D95%; E10%D90%; E15%D85% Biodiesel obtained from cottonseed	NA	At initial blends heat release values are lower further increases during stroke expansion for EXDy blends	Increases with the help of increasing blending	Uniform for ExDy blends	Slightly reduces	98
E5%D95%; E10%D90%; E15%D85% Madhuca indica flower feedstock for bioethanol production	Duration of combustion decreases by increasing the bioethanol percentage	The maximum heat release value found in 15% blending followed by 5% and 10% blending	At all blending its higher	By increasing bioethanol blending cylinder pressure increases	NA	49
E5%D95%; E10%D90%; E15%D85%; E20%D80%	By increasing bioethanol combustion duration decreasing	NA	Decreases by increasing bioethanol blends	It decreases with CN improver	NA	47
E5%D95%,E10%D90%;…..E45%D55% By using HPSS@1bar and LPSS@0.1 bar two fuel supply	By increasing bioethanol fraction it decreases in both the cases	NA	It increases with increase in bioethanol blending.	By increasing bioethanol amount and supply pressure it is higher	NA	51
WPFE5%; WPFE10%; WPFE15%; WPFE 20%; WPFE25% Waste pomegranate for production of bioethanol	By comparing with pure gasoline with 10% blend the value is low also for 25 % blending it is highest.	15% blend have maximum heat liberated followed by 10% blend	NA	By increasing percentage of blend indicated power increases	NA	54
E10%G90%; E20%G80% ; E30%G70% ;E40%G60% Effect on SI engine performance and emissions by using bioethanol-gasoline blends	NA	NA	NA	NA	NA	55
E5%G95%; E10%G90%; E15%G85%; E20%G80%; E50%G50% Effects on a review on performance spark ignition engine on bioethanol Blends	NA	The heat release rate is better with increase in blending	NA	In case of gasoline the peak pressure is faster due to lower octane rating	NA	56
E10%G90%; E20%G80%; E30%G70%; E40%G60%; E50%G50% Study for the effect of bioethanol-gasoline blends on emission and engine performance	NA	NA	NA	NA	NA	57

RoHR= Rate of heat release; Pcyl: In-cylinder pressure; Tcyl: In-cylinder temperature; DoC = Duration of combustion; ID: Injection delay

Table 5: Engine Performance

Different blending samples	BSFC	BTE	BP	EGT	VE	IMEP	Ref
E5%D95%; E10%D90%; E45%D55% By using HPSS@1bar and LPSS@0.1 bar two fuel supply	In HPSS up to 35% blending with diesel the value of BSFC increases, for LPSS: it increases with increase of bioethanol blending.	When using HPSS the maximum increase at 35% bioethanol	NA	NA	NA	HPSS: It is almost constant up to 35% bioethanol. With increasing bioethanol amount, cycle variation expressed as COVIMEP, LPSS: By increasing bioethanol it decreases slightly.	51
E5%D95%; E10%D90%; E15%D85% Madhuca indica flower for Bioethanol production	Higher for 25% blend at lower concentration of blending it decreases.	NA	NA	By increasing bioethanol load it increases slightly Slightly	NA	NA	49
WPFE5%; WPFE10%; WPFE15%; WPFE 20%; WPFE25% Waste pomegranate for production of bioethanol	NA	In comparison with other blends 15% blend achieves the best thermal efficiency	As compare to pure fuel 20% blending has the maximum engine power	NA	At lower speed 1300 rpm, 25% blend produces maximum volumetric efficiency, at high engine speed 1800 rpm 15% blend produces lower volumetric efficiency.	By increasing blend from 10% to 15% mean effective pressure is increasing	54
E10%G90%; E20%G80%; E30%G70%; E40%G60% Blending effect of bioethanol-gasoline and its performance and emissions	As compare to gasoline the minimum BSFC value was decrease by 17.21%	BTE increases upto 40% blending	To improve engines power output increasing blending of bioethanol was useful	NA	NA	NA	55
E5%G95%; E10%G90%; E15%G85%; E20%G80%; E50%G50% Effects on a review on performance spark ignition engine on bioethanol Blends	With the help of increasing bioethanol blend it decreases brake specific fuel consumption	5% & 10% blends has more brake thermal efficiency than that of gasoline	NA	NA	The volumetric efficiency is seen to be more by 5 to 10% than that of gasoline	NA	56
E10%G90%; E20%G80%; E30%G70%; E40%G60% ; E50%G50% Effect of bioethanol/ gasoline blends emissions and engine performance and	SFC value increased upto 40% blend	NA	NA	NA	NA	NA	57

Table 6: Emissions

Different blending samples	NOx	Smoke	CO	UHC	PM	CO2	Ref
E5%D95% ; E10%D90%; …... E45%D55% By using HPSS@1bar and LPSS@0.1 bar two fuel supply	By increasing bioethanol blending NOx value increases until the combustion process start deteriorate.	NA	In HPSS it decreases 8 times and in LPSS it decreases 5 times	In case of HPSS-1 bar it increases for 20-35%.	NA	It is higher at HPSS, it decreases by increasing bioethanol blend.	51
E20%B80%; E40%B60% Without deteriorating the thermal efficiency by using Exhaust gas recirculation	By increasing bioethanol blending it decreases	By increasing bioethanol blending it decreases	Slightly increases for B60E40.	Slightly increases	NA	NA	58
E10%D90% For LHR (low-heat-rejection) conditions a test engine modified	Lower	Lower	NA	NA	NA	NA	59
E5%D95%; E10%D90%; E15%D85%	As bioethanol blend increases NOx value decreases	By increasing bioethanol blending smoke value decreases	NA	Lower for 5% Higher for 10%	NA	NA	59
WPFE5%; WPFE10%; WPFE15%; WPFE 20%; WPFE25% Waste pomegranate for production of bioethanol	As compare to gasoline the NOx emission was found higher for all speeds	NA	For 25% blending maximum reduction in CO was observed	As compare to 25% and 15%, 20% blend has lowest hydrocarbons	NA	CO_2 emission reduces as bioethanol contains low carbons	54
E10%G90%; E20%G80%; E30%G70%;E40%G60% Effect of gasoline blends on SI engine	The maximum NOx reported was 20.91 with 40% blend at 2500 rpm engine speed	NA	At 30% blending CO was reported 26.3% at 2500 rpm engine speed	At 40% blending 31.05% UHC value was reported at 2500 rpm engine speed	NA	For 40% blend CO_2 deviation was 42.5% for speed 1500 rpm	55
E5%G95%; E10%G90%; E15%G85%; E20%G80%; E50%G50% A review on effects of bioethanol blends on SI engine	At 15% blending NOx emission decreases by about 83%	NA	By increasing the use of blend in the engine the cleaner it becomes with respect to CO	By increasing bioethanol blend UHC decreases	NA	By increasing blending CO_2 emissions was decreased	56
E10%G90%; E20%G80%; E30%G70%;E40%G60% ; E50%G50% Effects of bioethanol gasoline blends on the performance and emissions	NA	NA	With the use of 50% blend CO values showed a decrease	HC values showed a decrease of more than 50% with the use of E50 fuel.	NA	CO_2 emissions increased at rates up to 50% with the use of bioethanol.	57

Table 7: An overview for the effect of bioethanol gasoline blending and operating conditions for NOx emissions in SI engine

Engine type	Bioethanol blending in gasoline	Process parameters	Study for NOx	Ref.
1C, CR= 8:1	0%, 5%, 20%	IMEP=4.5 bar	E% ⇨ decreases	60
EIS, CR=8.2:1	0% to 100%	At full engine load it was open loop control; At part engine load it was close loop	E% ⇨ decreases	61
C, 4S	0%, 1.5%, 12%	ES: 1500 rpm, CR= 7.7:1 & 8.2:1	E% ⇨ decreases	62
1C, CR=8:1 to 9:25	0% to 30%	ES = 1500 rpm	E% ⇨ decreases	63
1C, 4S	0% to 100%	ES= 1500 to 4000 rpm, CR=6:1 & 10:1	E% ⇨ decreases	64
1C, 4S, CR=5:1 to 13:1	0%, 50%, 85%	ES=1000 to 5500 rpm, CR=10:1 & 11:1	E% ⇨ decreases	65
4C, CR=9.7:1	0% to 20%	ES=1000 to 5000 rpm	E% ⇨increases	66
4C, CR=10.5:1	0%, 85%, 100%	ES=3500 rpm	E% ⇨ decreases	67
1C, CR=11.3:1	0% to 15%	ES=2500, 5000, 6500 rpm	E% ⇨ decreases	68
DI, TC	0% to 20%	At steady-state conditions	E% ⇨ decreases	69
DI, CR=12:1	0%, 25%, 50%, 85%	At steady-state conditions	E% ⇨ decreases	70
4C, CR=12:1	22%, 100%	ES=2500 to 6000 rpm	E% ⇨ increases	71
3C, 4S, CR=8.7:1	0%, 50%, 60%	ES=2000 to 2800 rpm	E% ⇨ decreases	72
1C, CR=9.5:1	0% to 100%	ES=2000 rpm	E<25% ⇨ increases E>25% ⇨ decreases	73
4C	0% to 85%	Constant engine speed	E% ⇨decreases	74
CR=9.8:1	0% to 40%	Cold start condition	E<10% ⇨ increases E>10% ⇨ decreases	75
1C, CR=10.5:1	0% to 20%	ES=2000 rpm	E% ↑ ⇨ decreases	76
4S, CR=11.5:1	0% to 100%	ES= 1500 RPM IMEP=3.4 bar	E% ↑ ⇨ decreases	77
1C, 4S	0% to 80%	ES=2000 rpm	E% ↑ ⇨ decreases	78
4C, 4S, CR=10.4:1	0% to 10%	WP=5-20 kW Speed=80 to 100 km/h	E% ↑ ⇨ decreases	79
1C, 4S, CR=9.8:1	0%, 24.3%, 48.4%, 60.1%	ES= 3500 to 5000 rpm	E<24% ⇨ increases E>24% ⇨ decreases	80
1C, CR=10.5:1	0% to 40%	ES=2000 rpm	E% ↑ ⇨ decreases	81
4S, CE and FIE	0%, 15%	Speed of engine kept constant	CE ⇨ decreases FIE ⇨ increases	82

1C, CR=10.5:1, AC	0%, 100%	ES=1600 to 3600 rpm	E% ⇨ decreases	83
1C, 4S, CR=5.1:1	0%, 10%	ES=3000 rpm	E% ↑ ⇨ decreases	84
4C, CR=10:1	0%, 15%	ES=1000 to 6000 rpm	E% ↑ ⇨ decreases	85
1C, 4S CR=9.6:1	0%, 10%, 30%, 60%	ES= 1200 rpm, BMEP=3 & 5 bar	E% ↑ ⇨ decreases	86
4C, 4S, CR=8.8:1	0% to 30%	ES=2000 to 4500 rpm	E% ↑ ⇨ decreases	87
4C, 4S	0% to 30%	Under cold and hot conditions	E% ↑ ⇨ decreases	88
4C, 4S, CR=10.2:1	0% to 20%	Under steady-state conditions	E% ↑ ⇨ decreases	89
4C, 4S, CR=9.6	0% to 20%	ES=1000 to 5000 rpm, Different spark timing, and throttle angle	Throttle angle ↑ ⇨ decreases, spark timing ↑ ⇨ decreases, RPM ↑ ⇨ decreases	90
1C, 4S, CR=10.0	0% and 20%	ES=1500 rpm, Loads: 33, 58, and 83%	Load ↑ ⇨ increases	91
4C, 4S, CR=7,	0% and 10%	ES= 1600 to 2400 rpm, full load	Max NOx was recorded at 2500 rpm, E% ↑ ⇨ increases	92
4C, 4S, CR=9.5	0% to 30%	ES=3000 rpm, load 40%	E% ↑ ⇨ decreases	93
1C, 4S, CR=10:1	0% to 25%	ES=1300 to 1800 rpm	E% ↑ ⇨ increases	94
1C, 4S, CR=8.5	0% to 40%	ES=1500 to 2500 rpm, Idle load	E% ↑ ⇨ decreases Engine speed ↑⇨ increases	55
4C, 4S, CR=10.5	0% to 50%	ES=1000 to 6000 rpm load 0 to 100%	Engine speed ↑ ⇨ increases, E% ↑ ⇨ increases	95
1C, 4S, CR=7	0% to 100%	ES= 2500 rpm, Engine load 2, 2.5, 3, 3.5, and 4 Nm	E% ↑ ⇨ increases	96
4C, 4S, CR=9.6	0% to 100%	ES=2100 rpm, ignition timings=5	E% ↑ ⇨ decreases, Advancing ignition timing↑ ⇨ increases	97

- ES: Engine speed

➢ Effect of bioethanol blend on the engine performance

a) The blending of bioethanol and gasoline causes fluctuations in thermal brake power. At lower blends and lower engine speed BTE first increases while for increasing blend it decreases over the entire speed range.

b) As compared to pure gasoline fuel, the maximum reduction in brake-specific fuel consumption shows 17.21% for a 40% blend.

c) The mechanical efficiency increases by increasing bioethanol blending. As compare to gasoline a blending of 10% and 15% produces higher mechanical efficiency. At engine speed 1500 rpm mechanical efficiency increased later it decreased.

❖ Effect of bioethanol blend on Emissions

a) As compared to gasoline the exhaust emission was examined it was found that CO, CO_2 and HC values decreased up to 50% in the use of 10% and 50% blends.

b) It can be seen that each 5% increase in bioethanol blend decreases near about 6% emission of unburnt hydrocarbons.

c) From the above study, it is observed that engine power and engine torque decreased up to 20% with the use of 50% blending.

d) When bioethanol blending concentration increases NOx emission levels of SI engine decreases due to lower heating value and higher latent heat of vaporization in bioethanol/ gasoline blends. Also note that bioethanol has fewer carbon atoms than gasoline, so as the bioethanol blend increases, NOx emissions decrease. Compared to gasoline, the combustion process of a bioethanol blending requires less air under stoichiometric operating conditions.

e) As compare to gasoline bioethanol has higher value of RON so higher compression ratios can be used with SI engines.

❖ Furthermore, this review equally points out some limitations of using bioethanol/ diesel blends.

a) Several properties such as CFPP, viscosity, stability and lubricity adversely affect the injection system.

b) Another important limiting factor is the low amount of cetane that affects combustion.

c) Various technical modifications to the fuelling system were required to avoid airlock. For the recovery of fuel vapours, a special system is required, since bioethanol is highly volatile, fuel storage and handling are problematic.

From the above study, for various engine specifications such as 2-stroke gasoline engine, 4-stroke gasoline engine, variable speed internal combustion engine, VCR gasoline engine, but the performance parameters depend on quality, operating conditions and engine specifications. Also, it can be studied that blending of bioethanol with gasoline is more significant than with diesel blending, with mostly 4 stroke engines with various range of following operating parameters.

Power requirement = 4.5 KW @ 1800 RPM

Speed range = 1200 to 1800 RPM

Compression range (CR) = 6:1 to 10:1

Therefore, this research is needed to optimize blending bioethanol with engine performance. About half of India's population is directly involved in this sector. This will increase the employment opportunities for accountants, helpers, legal counsel and chemical engineers as well as those directly involved in agriculture. Most importantly, it will bring more benefits to the country's farmers and lead to the balanced growth of the country, which is a major problem in today's economy.

Authors Contribution

All authors contributed to the study's conception and design. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare no competing financial interest.

Acknowledgments

The authors acknowledge Department of Science & Technology, Govt. of India, for financial support under sanction number SP/ YO/ 2019/ 1589 (G)

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