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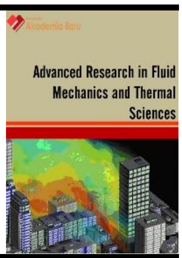

Effect of Ethanol-Gasoline Blends on Performance, Combustion and Emission Characteristics of Spark Ignition Engine

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ABSTRACT

The need for transportation is increasing every day. Production of automobiles is catering to this need. The fuels used by these automobiles are mainly petrol and diesel. Discharge of pollutants present in these fuels causing air pollution. Renewable fuels with lesser emission and comparably cheaper are required as an alternative to reduce environmental pollution. Ethyl alcohol is having larger oxygen content, low molecular weight, and high H/C ratios and can burn completely with oxygen. The thermal efficiency of the spark-ignition engine can be improved, and the exhaust emissions can be reduced by using Ethyl alcohol. The objective of the study is to study experimentally, the performance, combustion, and emission characteristics were investigated with E25, E30 and E35 ethanol-gasoline (Gasohol) blends on a single-cylinder, four strokes, computerized spark ignition engine fitted with eddy current dynamometer and a precisely adjusted exhaust gas analyser. Under various load, engine speed and compression ratio, the tests were conducted, and the results were recorded. The result shows improved performance parameters of the engine. E25 blend consumed less fuel compared to all blends at maximum speed and the BSFC was about 0.32 kg/kW-hr. The thermal break efficiency of ethanol-gasoline blends was found to be increased compared to gasoline. Maximum BTE was found to be 27.87% for the E35 blend.

1. Introduction

The use of vehicles within the transportation sector is increasing at a quicker rate. The vehicles are profoundly keen on fossil fuels. Diesel, Petrol, Natural Gas are the primary fossil fuels. These fossil fuels are depleting as they are conventional fuels. The exhaust emissions from the automobiles by using fossil fuels are CO, HC, NO_x, SO_2, Particulate matter, Soot particles, etc [1]. These emissions have an adverse result on the human body moreover as on the surroundings. These emissions are

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inflicting cancer, respiratory disorders, and, they are the leading reason behind global warming and acid rain. The value of crude oil is increasing day by day. India is 70% import-dependent for meeting its crude oil necessities. In order to reduce oil dependency and reduce exhaust emissions, the analysis was done for an alternative fuel to interchange the existing conventional fuel [2]. The alternative fuel ought to be clean, eco-friendly, and renewable. Vegetable oils and waste-derived oils are the promising substitute fuels for Diesel. Similarly, alcohols like ethanol and methanol are alternative fuels for Gasoline. In this work, Ethanol is employed as an alternative fuel by mixing it with gasoline and tested on an S.I engine.

The fundamental fuel discovered to be a progressively necessary alternative to petroleum is bio-fuel. It is biodegradable and delivers altogether less air contamination than fossil fuel [3]. Ethanol (C_2H_5OH) is a very important member of the biggest group of organic compounds referred to as Alcohol. Ethanol is made from biomass such as sugar ex. Sugarcane, biomass such as starch ex. Corn, biomass such as cellulose ex. Wood is renewable and produces terribly fewer emissions. Ethanol is comprised of a group of chemical compounds whose particles contain a hydroxyl group, OH, connected to a carbon molecule. Hence, the oxygen substance of this fuel supports the further combustion of petrol. Also, ethanol is usually used to increase gasoline's octane number [4, 5].

Because of incomplete combustion of fuel, and because of the absence of oxygen in combustion, most of the emissions are formed, petrol has no oxygen substance and oxygen for combustion is got from the intake air. During this approach, secondary oxygen is provided through ethanol blended in petrol as ethanol [6]. Ethanol has a much higher latent heat of vaporization (855 kJ/kg) than petrol (293 kJ/kg). As a result, the fuel mixture coming into the cylinder is far cooler and hence denser in case of ethanol than in the case of petrol. Ethanol has a higher-octane number (99) than petrol (80-100). As a result, 'pre-ignition' doesn't occur once ethanol is used [7].

Yusaf *et al.,* [8] examined experimentally and in theory by operating a 4 stroke S.I engine on ethanol-gasoline blends. Potato waste bio-ethanol was utilized in the experiment. The results concluded that the rise within the ethanol-gasoline blend rises the torque and power output of the engine. At varying speeds of engine 1000 to 5000 rpm, the concentration of CO and unburned hydrocarbons emissions were decreased in the tailpipe. Negi *et al.,* [9] investigated the engine performance characteristics with the ethanol-gasoline mix, by designing a cylinder by cylinder model in MATLAB. The results showed that ethanol-blended gasoline will increase brake power and brake thermal efficiency with the decrease in exhaust gas temperature. Tiwari and Shrivastava [10] calculated the performance parameters of single-cylinder, two strokes, air-cooled S.I engine with the ethyl alcohol and gasoline ratios of 10%, 20% and 30% by volume. Among all the blends, E10 shows higher performance. Amit Pal investigated by the ethanol-gasoline blend volume restricted to 5-15%. The results concluded that a low Gasohol blend can be used as a clean fuel to reduce CO, HC and NOx emissions from the tail pipe [11].

Bokhary *et al.,* [12] discovered the results of using ethyl alcohol unleaded gasoline blends on emissions and performance in an S.I engine. The study was directed on a single-cylinder, 4 strokes, German CT three hundred VCR S.I engine. The outcomes indicated that the performance of the engine has increased, with the rise in BP, BTE, volumetric efficiency, brake torque, and bmep and are higher compared to pure petrol by 11.06%, 18.16%, 1.54%, 11.99%, and 11.99% respectively. Kumar *et al.,* [13] through an experiment evaluated the results of ethyl alcohol-gasoline blends with 5%, 10%, 15%, 20% volume on the performance of the S.I engine. It was determined that among the four blends, E10 is the best blend and may be used further in S.I engines. Ibrahim *et al.,* [14] through an experiment examined the results of ethyl alcohol-petrol blends on the exhaust gas and performance characteristics of 4 cylinders, 4 strokes, S.I engine with a C.R of 6.7:1. With increasing engine speed, there was a decrease in BSFC for ethanol blend ratios of 5%-7.5%. For old engines, the acceptable blend is E7.5, which may be used as a substitute fuel. Da Silva *et al.,* [15] evaluated the effects generated by the addition of oxygenates such as ethanol, ETBE and MTBE and non oxygenates such as isooctane and toluene on the Reid vapor pressure (RVP) and Octane number. The results showed that Iso-octane and toluene reduced the blend's RVP and increased the Octane number. Patil *et al.,* [16] studied the impact of mixing composite additive on Gasoline fuel. The results concluded that as the percentage of additive increases, the A/F ratio, heating value and density of the sample decreases.

Demirbas *et al.,* [17] studied the effect of adding oxygenates, like MTBE, methanol, and ethanol to gasoline and concluded that the oxygenates cause terribly less pollution once they burn and are cleaner fuels. Kheiralla *et al.,* [18] investigated the effect of ethyl alcohol-petrol blends on properties of fuel of the variable speed S.I engine. The results concluded that the blends densities and kinematic viscosities enhanced continuously and linearly with an increasing percentage of ethanol.

Menon *et al.,* [19] investigated the impact of lower gasohol blends (up to 30% by volume) on emission and performance characteristics of the one cylinder, four strokes S.I engine. The results concluded that E20 is the most efficient and economical ethanol blend and might be directly used for a four-stroke S.I engine. Sakthivel *et al.,* [20] used E0 and E30 blends and conducted experiments on a motorcycle with a chassis dynamometer. Under steady-state wide-open throttle condition, the performance, emission and combustion characteristics were examined. The results obtained showed that vehicle power reduced by 10% and there was an increase in fuel consumption by 5% with E30 blend compared to Gasoline, because of Lower calorific value. HC and CO emissions cut by 66% and 75% respectively with E30 compared to Gasoline. With E30 blend, NOX emission was increased about 2.5 times. E30 blend has a longer burn period, reduced heat release and peak pressure compared to Gasoline.

Nwufo *et al.,* [21] investigated the combustion, performance and emission characteristics of a one-cylinder S.I engine at full load conditions. The results have shown that the octane number was increased by the addition of ethyl alcohol to Gasoline, which in turn increased the C.R and power o/p and eventually leading to an increase of BTE of the blend. Reduction in HC and CO emission and increased CO_2 emission. Increased pressure and temperature of combustion improved combustion characteristics. Barakat *et al.,* [22] conducted experiments on a 4 cylinder, 4 stroke SI Vehicle car using 4 to 20 vol. % ethyl alcohol. At numerous engine speeds and ethyl alcohol concentrations the graph obtained was linear for fuel consumption (kg/hr) and ethyl alcohol concentration (vol%). The fuel consumption rate is higher in isomerate enriched blends compared to reformate-enriched ones. Wang *et al.,* [23], conducted various tests on a petrol engine fuelled with hydrous ethanol gasoline(E10W), Ethyl alcohol gasoline (E10) and pure gasoline (E0). The emission and combustion characteristics were examined. The conclusions are E10W has a higher peak in-cylinder pressure at high load compared to gasoline. E10W attenuated CO, HC and CO_2 emissions at low load conditions. E10W has a higher peak of in-cylinder pressure compared to E10. Additionally, NOX emissions were decreased for E10W at a torque range of 5 Nm to 100 Nm. Finally, they concluded that E10W fuel can be used as a possible substitute fuel for petrol engine applications.

Mourad *et al.,* [24] examined the performance of a petrol engine using different fuel blends of propanol gasoline. The tests were performed on a 4 stroke SI Engine at various operating limits. The blends of propanol gasoline used are 5%, 10%, 15% & 20% at a speed of 1000-5000 revolutions per minute at constant load. The results concluded that engine torque raised up to 3.6% and BSFC reduced up to 2.84% by using propanol gasoline blends. P15 and P20 mix reduced the CO and HC emissions by 10.87% and 14.18% respectively. P15 was the most effective blend among all the blends.

From the above literature review, it has been found that ethanol was blended with gasoline in various proportions ranging from E5 to E25 at higher engine speeds ranging from 1000 to 5000 revolutions per minute. It was clear that Blends with a lower percentage of ethanol showed better performance as well as reduced emissions compared to gasoline. The main purpose was to find a suitable blend that can improve engine performance as well as can reduce engine emissions to a larger extent compared to smaller blends such as E5, E10, etc. In the present study, Gasohol blends ranging from E25 to E35 are used and tests were conducted on single-cylinder, four-stroke gasoline engine at speeds ranging from 1200 rpm to 1800 rpm at a constant Compression ratio of 10:1 and maximum engine load, in the first case. In the second case Engine speed was kept constant at 1800 rpm and the Compression ratio was varied from 8:1 to 10:1. E25 blend showed maximum reduction in Brake specific fuel consumption and E35 blend showed maximum increased Brake thermal efficiency in both the cases. Similarly, E35 blend showed maximum reduction in Carbon monoxide and Hydrocarbon emissions and increase in carbon dioxide emissions in both cases. Investigations carried out to check the feasibility to use Ethyl Alcohol in a normal engine without any modifications.

2. Chemical and Physical Properties of Ethyl Alcohol and Gasoline

Table 1 shows the chemical and physical properties of ethyl alcohol and gasoline. The nature of ethyl alcohol is like that of petrol. Both are liquid, and therefore, storage and transport are alike. Both can be mixed easily and burnt. Ethyl alcohol is having more substantial oxygen content, low molecular weight, and high H/C ratios and is an oxygenated fuel. It will burn totally and quickly with oxygen. Because of these favorable properties, the thermal efficiency of the engine is improved, and therefore, the exhaust emissions are reduced.

Table 1
Chemical and physical properties of ethanol and gasoline

Properties	Ethyl alcohol	Gasoline
Chemical formula	C_2H_5OH	C_8H_{18}
Composition	(c) = 52% (H) = 13% (O) =35%	(c) = 85% (H) = 15%
Boiling Point, °C at 1bar	78	30-225
LHV, MJ/kg fuel	29	45.2
Density, kg/m^3	785	745
RON	111	90-98
MON	94	82
Stoichiometric A/F, mass	8.94	15.04
Auto-ignition temp, K	792	753
Latent heat of vaporization, kcal/kg	204	70-100

Source: Balki [25], Lande [2]

3. Methodology

The tests are conducted on a four-stroke, single-cylinder, computerized spark-ignition gasoline engine running under constant load, maximum compression ratio, and variable speeds within the initial case. In the second case, the engine was made to run beneath constant load, maximum speed, and variable compression ratio. Table 2 shows the specifications of the engine. Figure 1 shows the experimental set up with an exhaust gas analyzer. It is provided with a gasoline engine, dynamometer, and Multifuel tank. It contains a data acquisition system, a computer, an operating panel, and an exhaust gas analyzer [26].

Table 2
Engine specifications

Specifications	Details
Engine	Kirloskar Type
Engine power	4.50 kW
Engine max speed	1800 rpm
Cylinder Bore	87.50 mm
Stroke length	110 mm
Connecting rod length	234 mm
Compression ratio	10:1
No. of strokes	Four
No. of cylinders	Single
Speed type	Variable
Dynamometer type	Eddy current

Source: Apex Innovations Pvt.Ltd. Maharashtra

Fig. 1. Computerized S.I engine test rig with exhaust gas analyzer

Gasoline (E5) was purchased from a nearby gasoline pump and was blended with ethanol to prepare three totally different blends. Ethanol (99.9% pure) was purchased from a local chemical supplier. These Ethanol and gasoline proportions in different percentages are stirred in a magnetic stirrer at a speed of 500-600 rpm for about 5-7 minutes to create the subsequent blends. These are E25 (25% ethanol + 75% gasoline), E30 (30% ethanol + 70% gasoline) and E35 (35% ethanol + 65% gasoline) [26, 27] Guarantee cooling water flows for eddy current dynamometer, piezo sensor, engine cooling, and calorimeter. Begin the setup and run the engine at the no-load condition for 5-6 minutes. Turn on the PC and run "Engine soft." Step by step increase the throttle to full open condition and load the engine all the while maintaining engine speed at 1800 RPM. Wait for steady-state (for 5 min) and input the information in the "Engines soft." Bit by bit increment the load to reduce the speed in steps of 200 RPM up to 1200 rpm maximum. A progression of investigations was completed utilizing E25, E30, and E35 blends[29]. The compression ratio is kept maximum at 10:1. Once the engine achieved the settled operating condition, engine emission parameters, for example, CO, HC, CO_2 and NO_X and the Exhaust gas temperature from a precisely adjusted Exhaust gas analyzer were recorded. In the second part of the examinations, the engine speed was kept constant 1800 rpm, and the Compression ratio differed from 8:1 to 10:1 [28]. The load was likewise kept constant in each case. The outcomes and performance plots were seen in "Engine soft."

4. Results

4.1 Performance of S.I Engine Fuelled with E25, E30, and E35 Blends

Brake specific fuel consumption is defined as the fuel consumed for one KW power generation in one hour. Figure 2(a) shows the behavior of BSFC with increasing engine speed. From the graph, it can be determined that the BSFC increases as the ethanol percentage increases in the gasoline blend. This is because more power is produced at a higher speed. As the engine speed increases, BSFC decreases for all the blends. The utmost reduction in BSFC was found at 1800 rpm for the E25 blend and was about 0.32 kg/kW-hr. The decrease in BSFC is because of the rise in BTE and falls in the equivalence A: F ratio.

Figure 2(b) shows the behavior of Brake specific fuel consumption with a variable Compression ratio at a maximum engine speed of 1800 rpm and a maximum load of 9 kg. From the graph, it can be determined that as the compression ratio is varied from 8:1 to 10:1, the BSFC decreases for all the blends. The maximum reduction in BSFC was found at C.R of 10:1 for the E25 blend and was about 0.47 kg/kW-hr. As the calorific value of ethanol is lower, thus there is the additional fuel consumption of the ethanol-gasoline blends compared to gasoline.

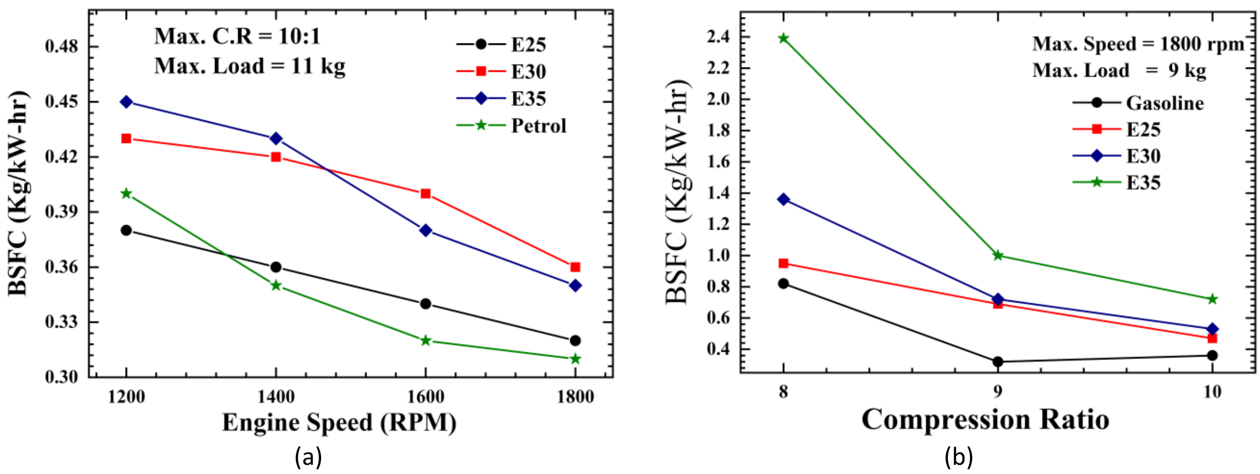
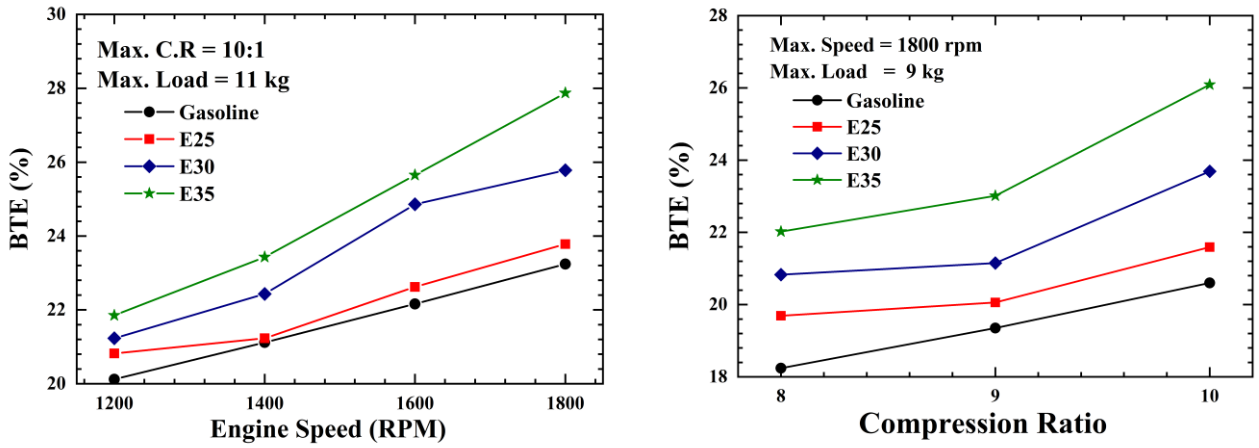


Fig. 2. (a) Variation of BSFC with engine speed and (b) compression ratio for various ethanol-gasoline blends

Brake thermal efficiency is a sign of output gain from given input energy. Figure 3(a) shows the behavior of BTE with increasing engine speed. From the graph, it can be observed that as the engine speed is increased, BTE will increase for all the blends and reaches a maximum at a speed of 1800 rpm. Maximum BTE was found to be 27.87% for the E35 blend. It had been detected that BTE at 1800 rpm using E25, E30, and E35 was increased by 2.32%, 10.93%, and 19.92% respectively in comparison to gasoline.

Figure 3(b) shows the behavior of Brake thermal efficiency with variable compression ratio at a maximum engine speed of 1800 rpm and a maximum load of about 9 kg. From the graph, it will be discovered that as the compression ratio is varied or increased, the BTE will increase for all the blends and was maximum at a compression ratio of 10:1. Maximum BTE was found to be 26.09% for the E35 blend. It had been discovered that BTE at C.R of 10:1 using E25, E30, and E35 was increased by 4.80%, 15%, and 26.65% respectively in comparison to gasoline.



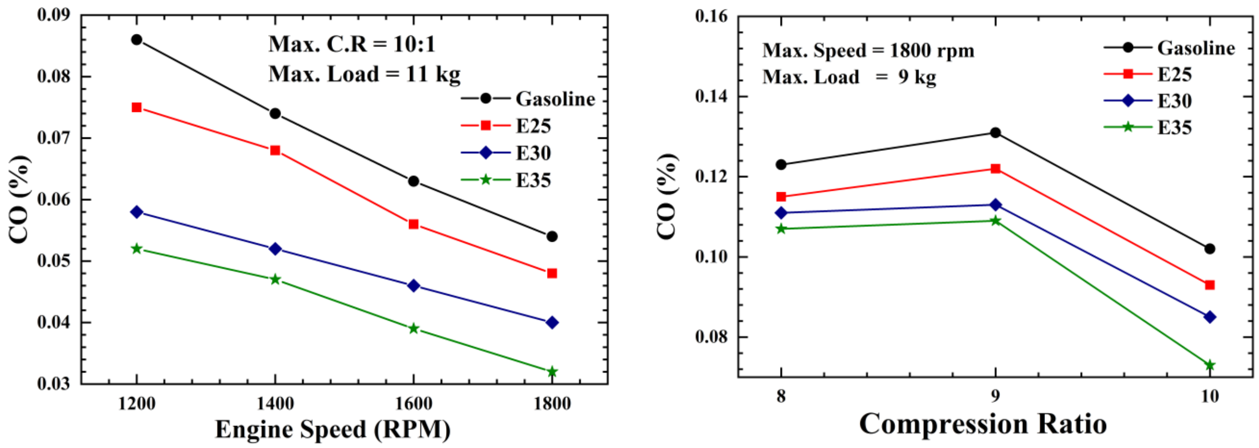
(a) (b)

Fig. 3. (a) Variation of BTE with engine speed and (b) C.R for various ethanol-gasoline blends

4.2 Emission Properties of S.I Engine Supplied with E25, E30, and E35 Mixture

Figure 4(a) indicates the concentration of CO emission for various engine speeds. From the graph, it may be concluded that the CO emission decreases with the rise in ethyl alcohol % in the fuel blend. This means that there is complete combustion with the ethanol-gasoline blend. The CO concentration at 1800 rpm using E25, E30, and E35 were decreased by 11.11%, 25.92%, and 40.74% respectively compared to petrol. The reduction in CO emission was because of the reason that ethanol contains less carbon than petrol.

Figure 4(b) shows the concentration of CO emission for variable Compression ratios at a maximum engine speed of 1800 rpm and a maximum load of 9 kg. From the graph, it may be concluded that the CO concentration increases at a C.R of 9:1, however, it decreases at a C.R of 10:1 with the rise in ethanol percentage in gasoline. The CO concentration at a C.R of 10:1 using E25, E30 and E35 were decreased by 8.82%, 16.66%, and 28.43% respectively compared to gasoline.



(a) (b)

Fig. 4. (a) Variation of CO with engine speed and (b) compression ratio for various ethanol-gasoline blends

Figure 5(a) shows the concentration of HC emission for various engine speeds. From the graph, it will be determined that, as the engine speed increases, the HC concentration decreases with the rise in ethyl alcohol proportion in the blend. The HC concentration at 1800 rpm using E25, E30, and E35 were decreased by 4.06%, 8.13%, and 17.88% respectively compared to gasoline. With the increment of the relative air-fuel ratio, there is a decrease in the concentration of HC emission.

Figure 5(b) indicates the concentration of HC emission for various Compression ratios at a maximum engine speed of 1800 rpm and a maximum load of 9 kg. From the graph, the HC emission decreases with increasing compression ratio and an increase in ethanol percentage in gasoline. The HC concentration at a compression ratio of 10:1 using E25, E30 and E35 were decreased by 4.68%, 10.15%, and 14.06% respectively compared to gasoline.

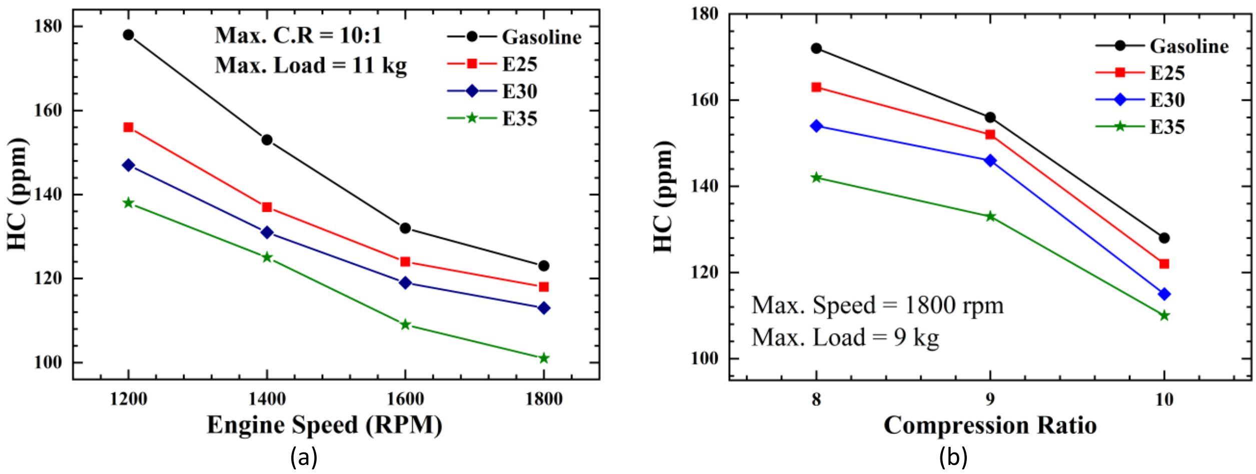


Fig. 5. (a) Variation of HC with engine speed and (b) compression ratio for various ethanol-gasoline blends

Figure 6(a) describes the concentration of CO_2 emission for different engine speeds. From the graph, it can be concluded that CO_2 concentration will increase with the increase in ethanol percentage. The utmost increase was found at 1800 rpm for the E35 blend. The CO_2 concentrations at 1800 rpm using E25, E30, and E35 blends was increased by 1.19%, 2.58%, and 3.98% respectively compared to gasoline. This is expected to decrease in carbon particle density in the mixed fuel and the large atomic diffusivity and high combustibility limits, which boosts blending procedure and consequently combustion efficiency.

Figure 6(b) describes the concentration of CO_2 emission for different compression ratios at a maximum engine speed of 1800 rpm and a maximum load of 9 kg. From the graph, it can be observed that the CO_2 emission is found to be increased at a compression ratio of 9:1, while it is found to be decreased at a C.R of 10:1 with the increase in ethyl alcohol percentage in gasoline. The CO_2 concentration at a compression ratio of 9:1 using E25, E30, and E35 blends was increased by 0.96%, 15.86%, and 23.07% respectively compared to gasoline.

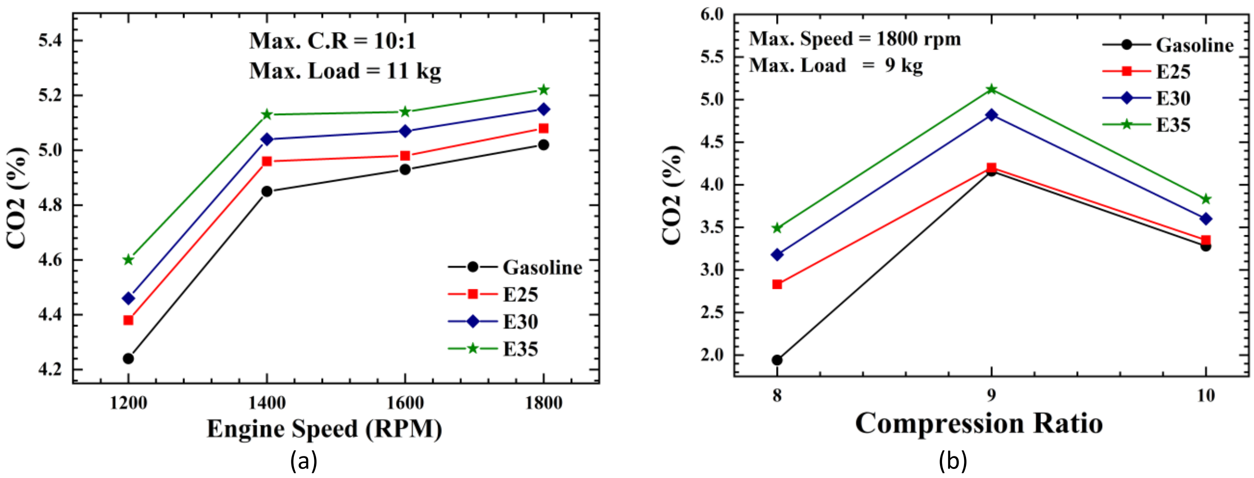


Fig. 6. (a) Variation of CO_2 with engine speed and (b) C.R for various ethanol-gasoline blends

4.3 Combustion Properties of S.I Engine Supplied with E25, E30, and E35 Mixture

Figure 7 shows the variation of cylinder pressure with respect to the crank angle for three different fuel blends (E25, E30, and E35) with varying engine speeds at a maximum compression ratio of 10:1. From the graph, it can be observed that the E25 blend has a higher cylinder pressure of about 28.5 bar among all the three blends. The higher cylinder pressure is accomplished as a result of more oxygen accessible in the chemical composition which enhances the combustion efficiency.

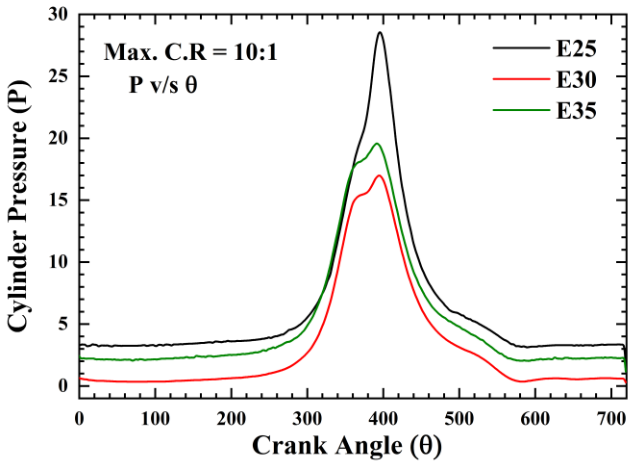


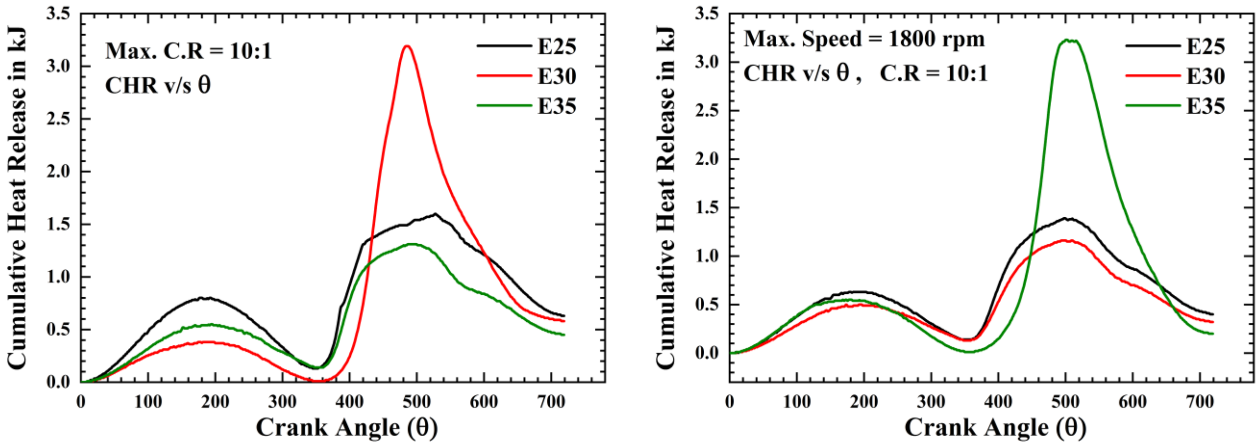
Fig. 7. Cylinder pressure vs. Crank angle for various ethanol-gasoline blends at varying engine speeds

The cumulative heat release is the total addition of instantaneous heat release rates. This curve has the characteristic S shape. The rate of heat release is slow at the start and increases rapidly till reaching a peak value then again slows down. Figure 8(a) shows the variation of CHR with respect to the crank angle for three completely different fuel blends (E25, E30, and E35) with variable engine speeds at a maximum compression ratio of 10:1. From the graph, it can be determined that the E30 blend has a higher cumulative heat release of about 3.19 kJ among all the blends.

Figure 8(b) shows the variation of Cumulative heat release w.r.t Crank angle for three completely different fuel blends (E25, E30, and E35) with a variable compression ratio at a maximum engine speed of 1800 rpm. From the graph, it can be observed that the E35 blend has higher cumulative heat release of about 3.23 kJ, while E30 contains a lower cumulative heat release of 1.16 kJ. Adding ethanol to petrol will prompt leaner better combustion.

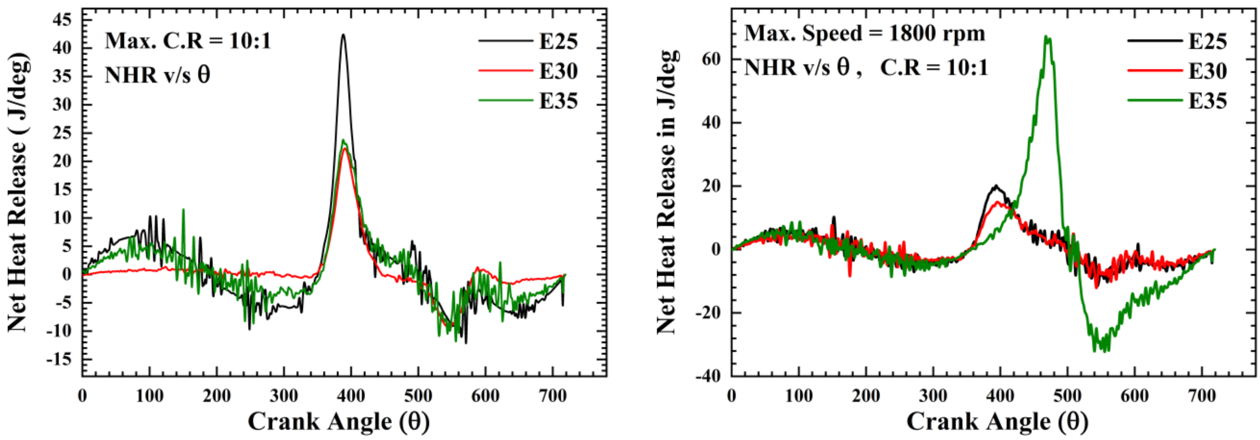
Figure 9(a) shows the variation of net heat release with respect to the crank angle for three different ethanol-gasoline blends (E25, E30, and E35) with varying engine speeds at a maximum compression ratio of 10:1. From the graph, it can be concluded that the E25 blend has higher net heat release of about 42.47 J/deg among all the blends, while E30 blend shows lower net heat release of 22.3 J/deg.

Figure 9(b) shows the deviation of net heat release w.r.t crank angle for three different fuel blends (E25, E30, and E35) with VCR at a maximum engine speed of 1800 rpm. From the graph, it can be observed that the E35 blend has a higher net heat release of about 67.84 J/deg among all the blends, while E30 blend shows lower net heat release of 15.02 J/deg. The lean combustion enhances the fulfilment of burning and along these lines, the CO concentration is relied upon to be diminished. The O_2 advancement created from ethyl alcohol expanded the O_2 proportion in the charge and prompt lean burning.



(a) (b)

Fig. 8. (a) Cumulative heat release vs. (b) crank angle for various ethanol-gasoline blends at varying engine speeds and C.R



(a) (b)

Fig. 9. (a) Net heat release vs. (b) **c**rank angle for various ethanol-gasoline blends at varying engine speeds and compression ratio

5. Conclusions

The following conclusions can be summarized from the above analysis

- The S.I engine performs satisfactorily on ethanol-gasoline blends without any modification to the engine.
- Engine performance parameters like Brake specific fuel consumption reduces with the gain in speed of the engine; however, the BSFC of the Gasohol blends are higher than gasoline. E30 blend consumes a lot of fuel than E25 at maximum speed. E25 blend consumes less fuel compared to all blends at maximum speed.
- The Brake thermal efficiency increases with the rise in ethanol proportion in gasoline. Among all the blends E35 offers maximum brake thermal efficiency at a maximum speed of 1800 rpm. E25 offers less BTE compared to all blends at maximum speed. The BTE of E25, E30, and E35 were increased by 2.32%, 10.93%, and 19.92% compared to gasoline (E0).
- CO and HC emissions decrease dramatically by ethanol addition because of the lean burning of the fuel, and because ethanol contains less carbon than gasoline. CO_2 emission increases because of the improved and complete combustion of fuel by the oxygen content existing in ethyl alcohol.

- The combustion method was found to be improved within the engine cylinder. The addition of ethyl alcohol to petrol resulted in leaner better combustion. The maximum cylinder pressure was 28.5 bar during the power stroke was obtained for the E25 blend. E30 blend has a higher cumulative heat release of 3.19 kJ. E25 blend has higher net heat release of 42.47 J/deg.
- It's not solely the price reduction by Ethanol blending that matters but also the millions of litres of petrol that we save for the future, and in a country like India, this is vital.
- Hence, the Spark Ignition engine will run on ethanol-gasoline blends without any alteration to the engine design and fuel system, and Ethyl alcohol will replace gasoline as an alternative renewable fuel.

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