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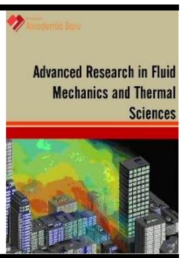

Experimental Investigation on the Performance of Single Spark Ignition and Twin Spark Ignition Engine Fuelled with Ethanol-Gasoline Blends

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ABSTRACT

Increasing the automobile population and contamination of the atmospheric air is a significant threat to the environment. Harmful emissions from the engine exhaust have considerably increased by manifolds. To bring down the pollution rate modern world demands much cleaner combustion with lesser amounts of emissions. Many investigations on IC engines have been conducted to discover such fuels that can efficiently replace the fossil fuels, produce higher heating value, and can burn to produce lesser or no harmful exhaust emissions. Also, a large number of engine modifications are being brought about to attain optimal performance values and reduced exhaust emissions but, the demand for lesser emission is a never-ending one. The investigational iteration for producing a better engine is an unstoppable one and proceeds to the next level with a small improvement in the result. Continuing to investigate in the same direction the current experimental work, investigates the performance characteristics of a single-cylinder engine with a single spark plug ignition and twin spark ignition respectively fuelled with blends of ethanol and gasoline. The experimentation was conducted at the engine's rated compression ratio. Engine performance characteristics were initially tested by combusting the fuel blends with only one spark plug while cutting off the second one. In the second stage of the experiment, a second spark plug additional to the earlier one was introduced into the combustion chamber. The engine's performance characteristics were tested under the same compression ratio and with the same blends of ethanol and gasoline fuel, similar to that used in the experimentation with a single spark plug. The experimental investigation demonstrated an improvement in the performance characteristics and also a decrease in the exhaust emissions with ethanol-gasoline blends and twin spark ignition engine.

Keywords:
Combustion; IC engine; Ethanol-gasoline blends; single spark plug; Twin spark ignition; compression ratio CO; NOx; CO_2; HC

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1. Introduction

Many research works conducted around different parts of the world have shown that the Transport sector around the world is one of the significant contributors to carbon dioxide (CO_2). It has always been a dream for many Researchers to invent a pollution-free engine, but a 0% emission-free engine could not be produced at all. Many initiatives, amendments, and strict enforcement have been taken since the early ’70s to reduce the harmful effects of engine exhaust emissions. Major investigations were made on improving engine efficiency and reducing exhaust emissions. In the later stages of research emphasis on finding a substitute for fossil fuels like gasoline and diesel, rose into prominence. Though many substitutes were investigated for their viability as fuels for IC engines, it was only alcohol that succeeded in the investigations. Methyl alcohol and Ethyl alcohol were widely suitable to be used as IC engine fuels. Methanol combustion does release a large quantity of formaldehyde in the emissions. Methanol production is a costlier and effective means in which it could be reduced still in process. Methanol is very much reactive, and if it comes in contact with the skin, it causes irritations, sours, and blemishes. Thus its use is very much limited or restricted.

Thus researchers shifted their concentration from methanol to ethanol. Ethyl alcohol or ethanol can be produced quickly and is less harmful even if it comes in contact with skin. It can be easily blended with gasoline in all proportions, and on combustion emits lesser formaldehyde as compared to that of Methanol. Ethanol has high evaporation heat, high octane number, and high flammability temperature; ethyl alcohol has a positive influence on engine performance [1].

The low Reid evaporation pressure of ethanol enables secure storage and safe portability. In spite of its positive effect when used in the gasoline engine, it is necessary to make some modifications to the engine, as alcohols quickly affect brass, bronze, and rubber products. As the ethanol content is increased in the ethanol-gasoline blend, the fuel consumption also increases; thus, the distance traveled by the vehicle decreases [2, 3].

From the literature survey, it was observed that the experimentation was conducted on a single-cylinder single spark plug engine using Ethanol-Gasoline blends in spite of the ethanol-gasoline blends emitted lesser regulated emissions than gasoline alone. At higher speeds, the engine emissions were high even with ethanol-gasoline blends. Thus the introduction of a second spark plug that would alternately fire at higher speeds was thought of. This framework has been the basis for the current investigation.

2. Literature Survey

Air pollution occurs mainly due to the pollutants emitted by the industries and the exhaust gases by automobiles. It was in the year 1952 that professor Haagen Smit proved emissions from the Automobile exhaust were one of the significant contributors to the increased levels of carbon monoxide (CO) and NO derivatives in the atmospheric air. With this, the emission norms were firstly imposed in California, and later it was followed by the later parts of the world. As compared to gasoline, using ethanol with gasoline in proper proportion has proved to improve engine efficiency, reduce the emission rate, and also extend the availability of gasoline [4-6].

2.1 Ethanol as an Alternative Fuel

Ethanol is one of the purest substances available in its natural state and has a chemical formula is C_2H_5OH. The presence of a hydroxyl group makes it behave as a partially oxidized hydrocarbon. From the investigations made by various researchers over the years, it has become evident that ethanol can be used as an alternative fuel in the IC engines either by blending it or as a whole. One such investigation conducted by Palmer [7] depicted that the power output was increased by 5% by adding 10% of ethanol; also, he claims that by adding 10% of ethanol, there was a significant reduction of CO to about 30%. Bata *et al.,* [8] from their investigations conclude that by adding ethanol to gasoline, the availability of oxygen to promote complete combustion will be enhanced, and this, in turn, reduces the quantity of CO and HC exhaust emissions.

Abdel Rehman *et al.,* [9], from their investigations on blends of ethanol-gasoline, have claimed that the addition of ethanol increases the octane number of the fuel but would bring down the blend's heating value. As the percentage of ethanol is increased in the ethanol-gasoline blend, the tenacity of resisting the knock will be improved, and thus the engine can be successfully operated at higher compression ratios. Alexandrian and Schwalm [10] have illustrated that blending ethanol with gasoline lowers the CO and oxides of nitrogen (NOx) values at costly fuel conditions, but the use of this blend often results in the emission of formaldehyde, acetaldehyde, and acetone. The effects of these emissions on the atmosphere are relatively less than that caused by the poly-nuclear emissions emitted by gasoline; this fact supports a higher percentage of ethanol blending with gasoline [11]. Effect of ethanol-gasoline blends on engine performance and exhaust emissions in different compression ratios, resulted in better thermal and brake efficiencies [12, 13].

Liu *et al.,* [14] studied the effects of E10 hydrous ethanol-gasoline blend on performance and emissions of a gasoline engine. M. Al-Hasan [15] conducted studies on the Effect of ethanol—Unleaded gasoline blends on engine performance and exhaust emission. Manzetti *et al.,* [16] wrote a review of emission products from bioethanol and its blends with gasoline. Saravanan *et al.,* [17] conducted experiments to study of combustion characteristics of an SI Engine Fuelled with Ethanol and Oxygenated Fuel Additives.

Schifter *et al.,* [18] undertaken the combustion characterization in a single-cylinder engine with mid-level hydrated ethanol-gasoline blended fuels. Suarez-Bertoa *et al.,* [19] investigated the impact of ethanol containing gasoline blends on emissions from a flex-fuel vehicle tested over the worldwide harmonized light-duty test cycle (WLTC). Venugopal *et al.,* [20] studied the Experimental study of the hydrous ethanol-gasoline blend (E10) in a four-stroke port fuel injected spark ignition engine.

Yucesu *et al.,* [21] studied the effect of ethanol-blended gasoline engine performance and exhaust emissions in different compression ratios.

Ruzi *et al.,* [22] investigated the exhaust emission in diesel engines such as Nitrogen Oxides (NOx), Carbon Dioxide (CO2), Carbon Monoxide (CO) and Particulate Matter using emulsion fuel made from low-grade diesel fuel.

2.2 Ethanol and Engine Components

Ethanol has a characteristic property of mixing with water in all proportions forming an immiscible mixture. When the immiscible mixture of ethanol-water blended with gasoline comes in contact with the engine parts, it may corrode the engine parts. Thus to use higher blends of ethanol-gasoline, the engine components must be mainly made up of materials that are lesser prone to corrosion [7]. Rubber has a higher affinity for ethanol. Hence all the rubber parts will be damaged with higher proportions of ethanol in the ethanol-gasoline blend. On reaction with ethanol, rubber deteriorates and forms a blockage in the flow line [8]. Thus, they should be replaced with materials that are non-reactive with ethanol.

2.3 Effect of Hydroxyl Group in Ethanol

The engine, when fuelled with different blends of ethanol-gasoline, shows an improvement in efficiency and decreased exhaust emission. With the increase in ethanol percentage in the ethanol-gasoline blend, exhaust emission reduces. The stoichiometric air-fuel ratio of ethanol gets significantly reduced to 2/3rd as that required for gasoline due to the presence of hydroxyl groups in ethanol. Thus, the exhaust emission is lowered due to the presence of the hydroxyl group [9], which readily aids the combustion process leading to complete combustion.

The auto-ignition temperature of ethanol is 3650C, and the flashpoint is 16.60C, while the auto-ignition temperature of gasoline is 28000C, and the flashpoint is -430C. Thus ethanol can be transported from one place to the other and can be easily stored. The latent heat of ethanol is nearly five times as high as gasoline; thus, it lowers the intake manifold temperature. This decrease in temperature is responsible for the increase in volumetric efficiency. With the increase in ethanol percentage, the volumetric efficiency of the engine is also seen to increase.

Ethanol has a calorific value of 29.7 MJ/kg, while gasoline has a calorific value of 45.5 MJ/kg; thus, the increased ethanol content in the ethanol-gasoline blend tends to decrease the heating value of the blend. Ethanol to produce an energy equivalent to that of Gasoline should be 1.5 times greater in volume as that of gasoline.

3. Experimental Procedure and Equipment

Experiments were carried on a 220CC Bajaj make Pulsar engine. It is a Single cylinder, four strokes, oil, and air-cooled engine, with twin spark ignition. The engine is coupled to an eddy current dynamometer. The engine output torque was measured with a digital tachometer. Fuel consumption by the engine was measured using a Burette mounted on the test panel. The detailed engine specifications are listed in Table 1, and the test rig is as shown in the Figure 1.

Table 1
Specifications of the test rig

Item	Specification
Engine	Type 4-Stroke, DTS-I, Oil Cooled, Single Cylinder
Engine Displacement (CC)	220 cc
Power (PS @ rpm)	20.76 bhp @ 8500 rpm
Torque (Nm @ rpm)	19.12 Nm @ 7000 rpm
Bore	67 mm
Stroke	62.4 mm
Rated Compression Ratio	9.5:1
No Of Cylinders	1
Valves (per cylinder)	2
Valve arrangement	Overhead camshaft
Fuel Supply System	Carburetor
Engine Cooling System	Oil cooled
Fuel Type	Petrol
Ignition	Digital Twin Spark

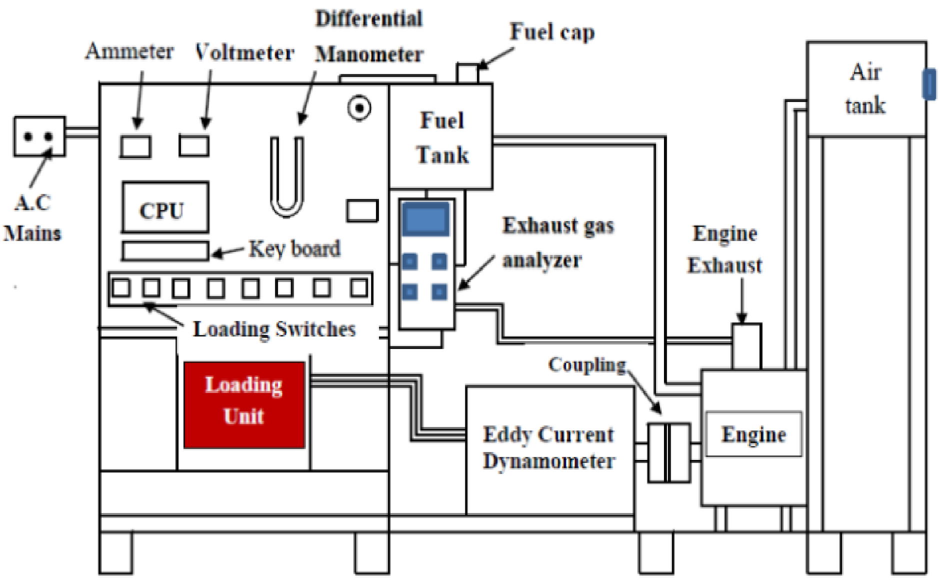

Fig. 1. Experimental setup

Experiments on the engine were conducted in two stages, in the first stage the experiment was conducted with a single spark plug, using regular petrol at the rated compression ratio of the engine; corresponding readings of the engine were noted. Then the experimentation was conducted with varying proportions of ethanol and gasoline blends starting from E0 (pure gasoline without ethanol) up to E35 (35% ethanol + 65% gasoline), the underrated compression ratio of the engine. Properties of gasoline and ethanol are listed in Table 2.

Table 2
Property of Gasoline and Ethanol

Fuel property	Gasoline	Ethanol
Formula	C_8H_{18}	C_2H_5OH
Molar C/H ratio	0.445	0.333
Molecular weight (kg/kmol)	114.18	46.07
Latent heating value (MJ/kg)	44	26.9
Stoichiometric air/fuel ratio	14.6	9
Auto-ignition temperature (°C)	257	425
Heat of vaporization (kJ/kg)	305	840
Research octane number	88–100	108.6
Motor octane number	80–90	89.7
Freezing point (°C)	40	114
Boiling point (°C)	27–225	78
Density (kg/m^3)	765	785

Anhydrous Ethanol, with a purity of 99.9%, is used as a blend with gasoline. The blend of ethanol and gasoline is prepared from E0, up to E35, containing 5% incremental proportions of ethanol in the blends. For the experimental work, an rpm of 1500 with an increment of 500 rpm starting from 1500 rpm was selected, and it was extending up to 9000 rpm. The blends are designated by alphabet 'E' to denote the ethanol content followed by a numerical indicating its volumetric percentage in the blend. In the second stage, experiments are conducted with regular gasoline and using a double spark plug. Corresponding readings at the rated compression ratio were noted down. Later the experiments were conducted with varying proportions of ethanol in ethanol-gasoline blends starting from E0 to E35, and corresponding readings were tabulated.

4. Results and Discussion

4.1 Effect of Ethanol-Gasoline Blends on Engine Torque

In the current experimentation, blends of ethanol-gasoline ranging from E00 to E35 are being used with a dual spark plug and single spark plug, respectively. The curve for engine torque developed at varying speed using blends of ethanol-gasoline as fuel in a single cylinder and single spark plug engine is as shown in Figure 2. With pure petrol and also with all the blends of ethanol-gasoline, it is observed that the engine torque initially increased to a maximum point touches the peak, and then from the peak point, it declines even though there is an increase in the engine rpm. Engine dynamics, quality, and quantity of charge admitted into the combustion chamber play a significant role in the reduction of engine torque. The engine torque increases with an increase in ethanol percentage in the blend. With E00, the maximum engine torque was noted to be 10.761 N-m at 3000 rpm. A maximum engine torque of 12.888N-m was found with E35 at 3000 rpm.

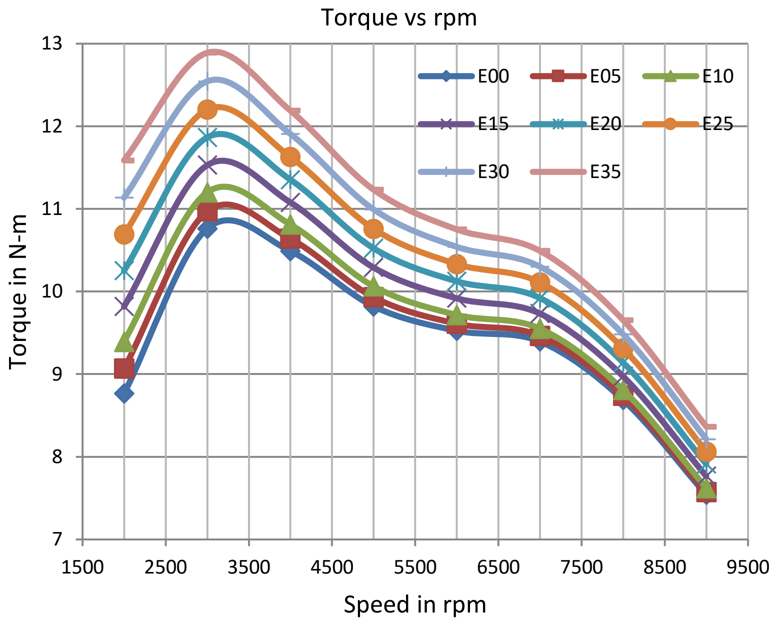

Fig. 2. Engine torque vs. speed for ethanol-gasoline blends in a single spark plug

The torque generated by the engine using a dual spark plug is shown in Figure 3. With the percentage increase in ethanol, the engine torque has also increased. The curve for torque developed is very much similar to that of the torque developed in a single-cylinder engine by using a single spark plug with varying ethanol-gasoline blends.

The engine torque initially increases to a maximum point, touches the peak, and then from that point, it declines even though an increase in the engine rpm takes place. With E00, the maximum engine torque was noted to be 11.193 N-m at 3000 rpm. With the increase in ethanol percentage, engine torque also increased considerably. A maximum engine torque of 13.531N-m was found with E35 at 3000 rpm.

With the use of an additional spark plug, complete combustion of the unburnt hydrocarbons (UBHC) is enunciated at higher rpm. The hydrocarbons that move out through the engine exhaust at higher rpm without getting combusted now leave the cylinder after they get combusted. Thus in comparison with the torque developed by a single spark plug engine, the torque developed by the twin spark plug engine is relatively more. By using a twin spark plug and E35 blend, an increase in torque by 21 percent was witnessed as compared to E00 at 3000rpm.

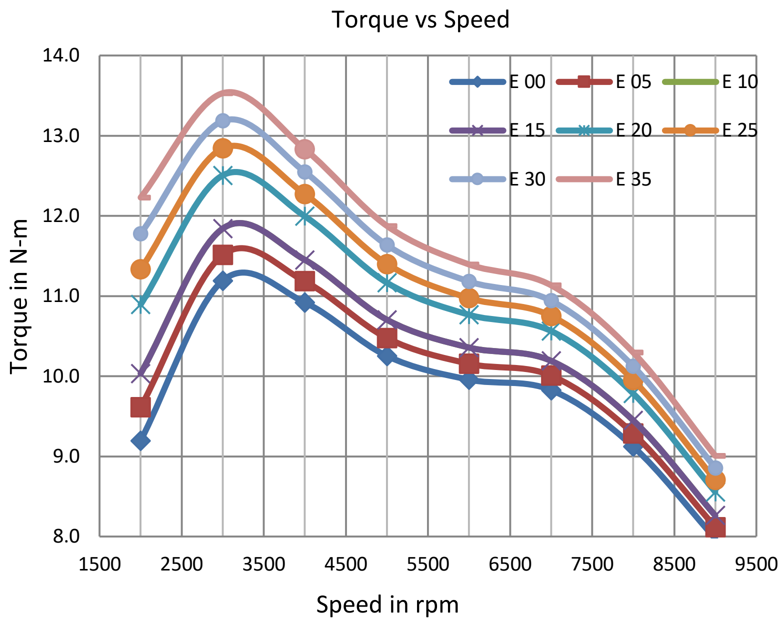

Fig. 3. Engine torque vs. speed for ethanol-gasoline blends in twin spark plug

4.2 Ethanol-Gasoline Blend's Effect on Brake Thermal Efficiency at Varying Speeds

Brake thermal efficiency is the quantity of heat available in an IC engine that is effectively utilized for doing mechanical work. Brake thermal efficiency of a single-cylinder engine using a single spark plug and fuelled with Ethanol-Gasoline blends is as shown in Figure 4.

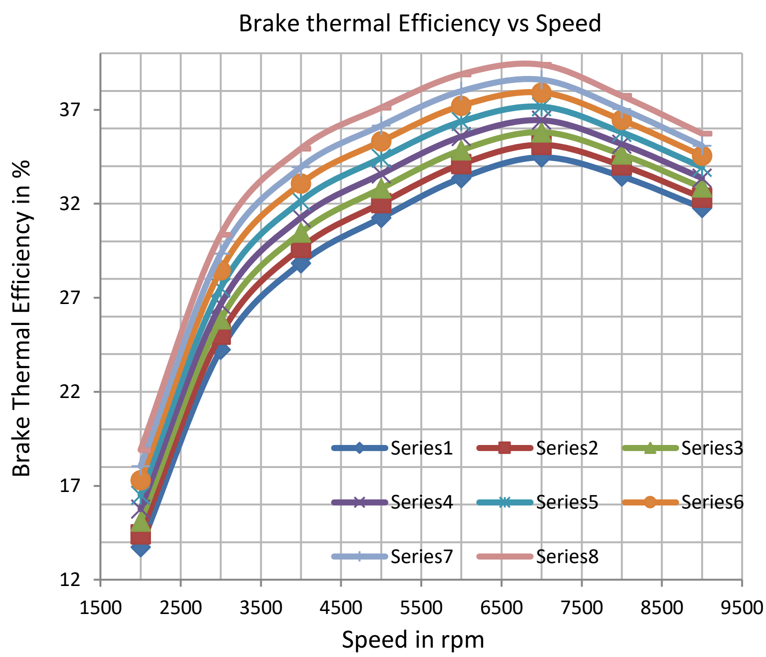

Fig. 4. Brake thermal efficiency vs. speed for ethanol-gasoline blends and single spark plug

Brake thermal efficiency is seen to increase with the increase in the engine speed, reaches a maximum value, and beyond that speed, the thermal brake efficiency of the engine decreases gradually and approaches a downhill.

The brake thermal efficiency curves of a single-cylinder engine with a twin spark plug, fuelled with ethanol-gasoline blends, are as shown in Figure 5. The maximum brake thermal efficiency of a single cylinder twin spark plug engine was 39.35% attained at 7000 rpm using the E35 blend. The maximum brake thermal efficiency using ethanol-gasoline blends and single spark plug was found to be 34.47% at 7000 rpm and E35 blend. At higher rpm's the partial air-fuel mixture that escaped into the atmosphere without getting combusted is now combusted by the additional spark plug. With the introduction of a second spark plug, an increase in brake thermal efficiency by 12 percent was observed.

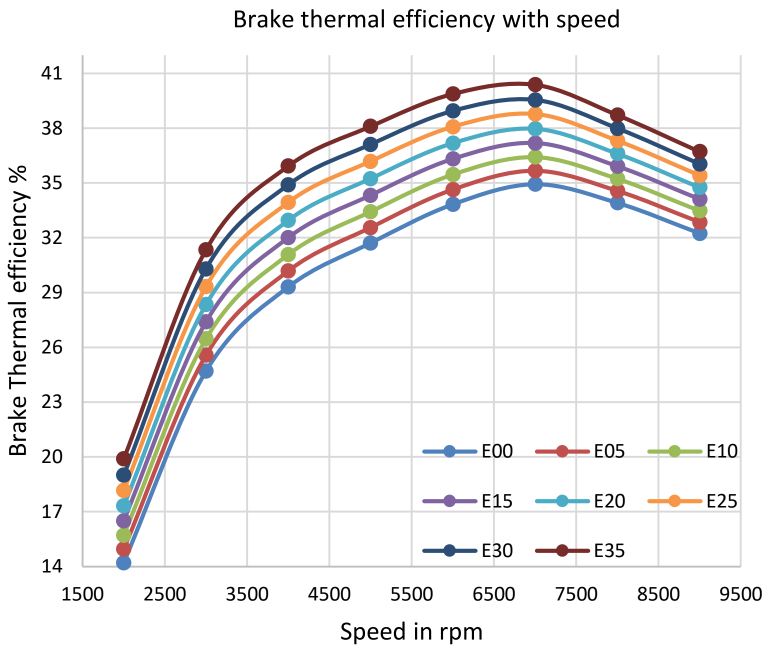

Fig. 5. Brake thermal efficiency vs. speed and for ethanol-gasoline blends and twin spark plug

4.3 Ethanol-Gasoline Blend's Effect on Brake Specific Fuel Consumption (BSFC) and BP

Brake specific fuel consumption (BSFC) is the measure of the fuel consumed by an IC engine to produce a known quantity of power output. BSFC goes on decreasing with the increasing ethanol percentage in the ethanol-gasoline blend. The curve obtained for various ethanol-gasoline blends using a single spark plug is, as shown in Figure 6. In comparison with regular petrol E00, the E35 blend yielded the best value of 0.239 kg/kWh as against 0.242 at 7000 rpm with a single spark plug. The value of BSFC decreased by 1.5 percent with E35as compared to E00. BSFC also decreased in twin spark plug engine fuelled with varying ethanol percentage in ethanol-gasoline blends. With regular petrol E00 as fuel in twin spark plug engine, the BSFC was noted to be 0.227 kg/kWh at 7000 rpm, and with E35 as fuel at the same rpm, the BSFC was found to be 0.224 kg/kWh the percentage decrease in BSFS was again 1.5%. BSFC percentage reduction with a twin spark ignition engine as compared to that of a single spark ignition engine is found to be 6% with both pure petrol E00 and ethanol-gasoline blend E35.

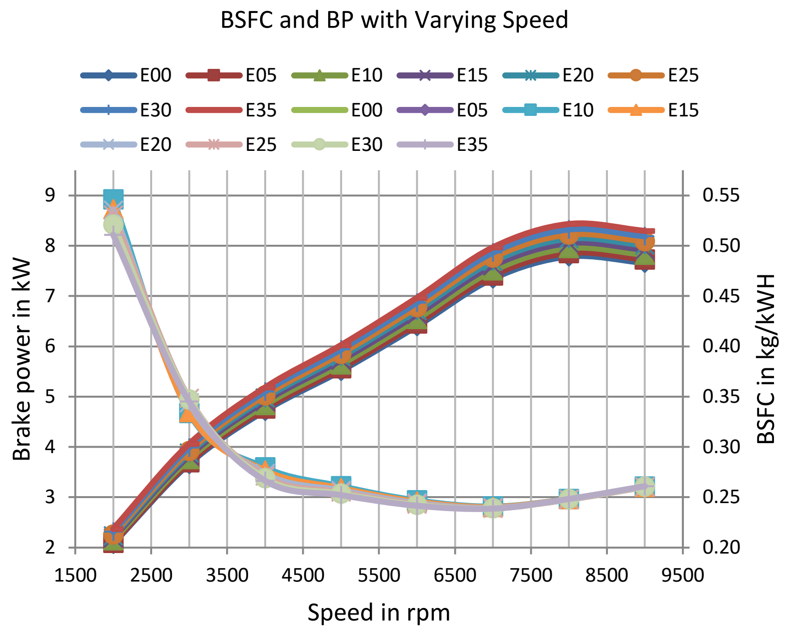

Fig. 6. Variation of BP and BSFC with speed using single Spark Plug

Brake power at different engine speeds is found to increase with an increase in the ethanol percentage in the ethanol-gasoline blend. The curves of brake power with single and twin spark plugs obtained at varying speeds and different blends of ethanol-gasoline are portrayed in Figure 6 and Figure 7, respectively. It is seen that the brake power increases gradually with increasing speed reaches a maximum value and then finds a gradual downfall even with the increase in engine speed. This positive gain of the Brake power is mainly because of an increase in indicated mean sufficient pressure and the in-cylinder pressure. This increase is achieved because of increased ethanol content in the blend. Ethanol possesses a higher heat of evaporation than that of gasoline, as a result of this, the charge gets cooled, and its density increases; thus, the higher output power is attained.

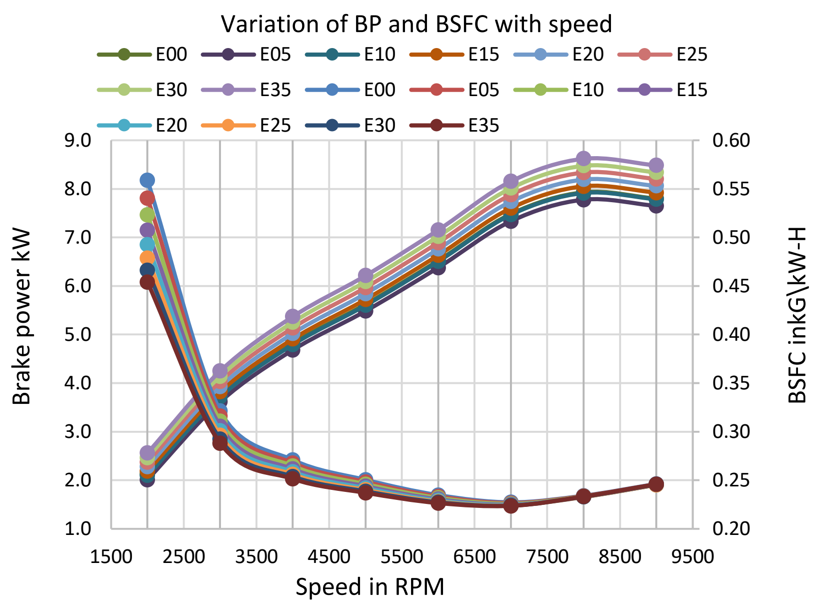

Fig. 7. Variation of BP and BSFC with speed using Twin Spark Plug

4.4 Ethanol-Gasoline Blend's Effect on CO Emissions

One of the primary sources of carbon monoxide emission in India is the increasing vehicle population. Carbon monoxide is colorless, tasteless, and smells less toxic emission from an engine. It is the result of incomplete combustion taking place in an engine. CO emission is considered to be a loss as a large number of fuel particles escape without actually getting combusted.

This incomplete combustion is mainly due to an insufficient oxygen supply. With the addition of ethanol, the CO emission will become lesser due to the presence of a hydroxyl group. This hydroxyl group supports the combustion process. Due to this fact, with the percentage increases in ethanol, the rate of CO emission decreases.

The curves of CO vs. varying speed using a different percentage of ethanol in ethanol-gasoline blends in a single spark plug engine and a twin spark plug engine is as shown in Figure 8 and Figure 9, respectively. With pure petrol and a single spark plug, the CO emission is initially high when the vehicle is just started. As the speed advances, the CO emission is reduced.

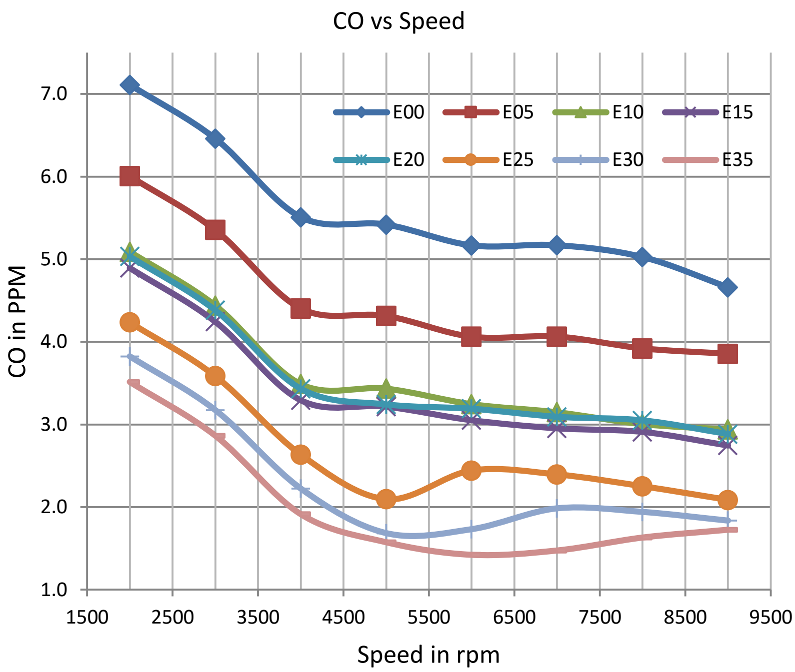

Fig. 8. Effect of Ethanol-gasoline blend on CO emission using a Single Spark Plug

Higher CO emission is seen in all the engines when it starts from rest because, during starting conditions, the engines demand a rich mixture. Under such circumstances, there is an oxygen-starved situation created that leads to higher CO emission. As the speed increases, the vehicle does not require rich mixture; thus, CO emission decreases as there is a sufficient quantity of oxygen available to combust the fuel particles.

It is fuelling varying ethanol-gasoline blends in a Twin spark plug engine results in decreased CO emission. The essential reasons for this reduction in CO emission are the hydroxyl group that increases with an increase in ethanol content and the spark from the additional spark plug. The second spark plug aids in the combustion of unburnt hydrocarbons at higher rpm.

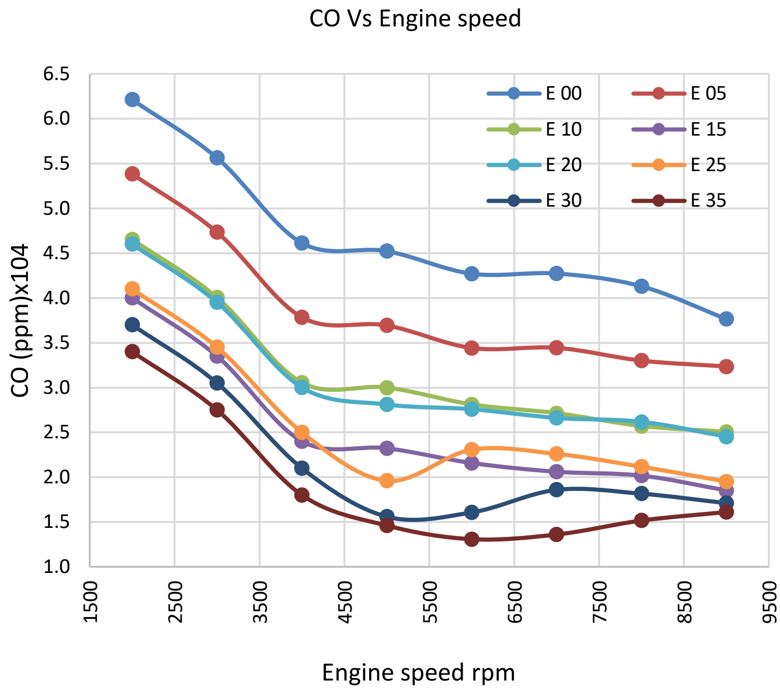

Fig. 9. Effect of Ethanol-gasoline blend on CO emissions using Twin Spark Plug

Initially, when a single spark plug engine fuelled with pure petrol was started, the quantity of CO emitted was 7.1100 ppm at 2000 rpm, and as the ethanol percentage increased from E00 to E35, a maximum CO emission of 3.5140 ppm was noted at 2000 rpm. Reduction in CO emission from pure petrol E00 to E35 was found to be 51 % with a single spark plug engine. With a twin spark plug engine, the initial reading was found to be 6.2150 ppm with pure petrol E00, and with E35, it was observed to be 3.9150. The reduction in CO emission with twin spark plug engine was found to be decreased by 45%, at 2000 rpm.

The twin spark-ignition engine, in comparison with a single spark ignition engine, showed a reduction in CO emission by 12% with E00 fuel and 3% with E35 fuel blend, respectively.

4.5 Ethanol-Gasoline Blend's Effect on CO_2 Emissions

Carbon dioxide is released into the atmosphere not only due to the intervening actions of human beings but also by nature itself. Carbon dioxide forms the principal constituent of exhaust emissions of all engines.

In the current experimental investigation, the curves of CO_2 emission using blends of ethanol-gasoline in a single spark ignition engine are as shown in Figure 10. Initially, when the engine is started, the CO_2 emission will be less, and as the speed of the engine increases, the CO_2 emission will increase to a maximum position, and then it decreases gradually with increasing engine speed. The CO_2 emission was found to be 6.8900 ppm and 8.6370 ppm with a single spark plug at 2000 rpm. On using E35 blend in a single spark plug ignition engine, it yielded a CO_2 emission of 5.4250 ppm and 5.2727 ppm, respectively. As the engine rpm was increased from 2000 rpm to 9000 rpm with E00 as fuel, the CO_2 emission was found to be increased by 20%. With the E35 blend and between an rpm range of 2000 to 9000, the CO_2 emission was found to be 3%.

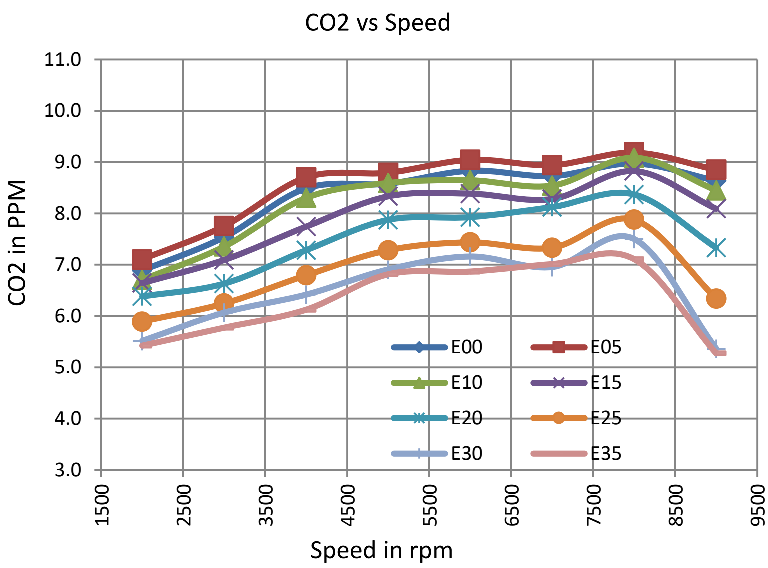

Fig. 10. Effect of Ethanol-gasoline blend on CO emissions using Single Spark Plug

In the current experimental investigation, the curves of CO_2 emission using blends of ethanol-gasoline in a single spark ignition engine are as shown in Figure 11. Initially, when the engine is started, the CO_2 emission will be less, and as the speed of the engine increases, the CO_2 emission will increase to a maximum position, and then it decreases gradually with increasing engine speed. The CO_2 emission was found to be 6.8900 ppm and 8.6370 ppm with a single spark plug at 2000 rpm. On using E35 blend in a single spark plug ignition engine, it yielded a CO_2 emission of 5.4250 ppm and 5.2727 ppm, respectively. As the engine rpm was increased from 2000 rpm to 9000 rpm with E00 as fuel, the CO_2 emission was found to be increased by 20%. With the E35 blend and between an rpm range of 2000 to 9000, the CO_2 emission was found to be 3%.

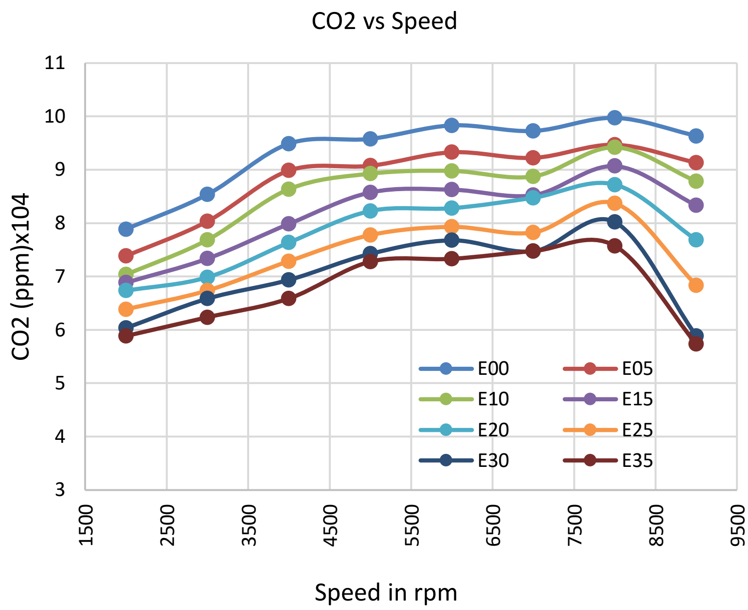

Fig. 11. Effect of Ethanol-gasoline blend on CO emissions using Twin Spark Plug

With an increasing percentage of ethanol content in the ethanol-gasoline blends, the carbon dioxide percentage in the exhaust of the engine should increase. But in the current investigation, the percentage of carbon dioxide is seen to be decreasing with the increasing ethanol content. This shows the chances of aldehydes like Acetaldehyde (C_2H_4O) and formaldehyde (CH_2O) formation.

The twin spark ignition engine, when tested with varying proportions of ethanol in ethanol-gasoline blends, yielded the same results as with that of the single spark plug engine with the only difference in the percentage of CO_2 Emission. By using E00, the CO_2 emission was found to be 7.8850ppm at 2000 rpm and 9.6327 ppm at 9000 rpm, which is an 18% increase from a starting point to the maximum rpm. With E35, the CO_2 emission was found to be 6.8900 ppm and 8.6377 ppm for 2000 rpm and 9000 rpm respectively, which is again a 20% increase in CO_2 emission. In comparison with the single spark plug engine, the twin spark ignition engine produced an increase in the percentage of CO_2. Thus one can arrive at the point that with the addition of a second spark plug, the formation of aldehydes can be prevented.

4.6 Ethanol-Gasoline Blend's Effect on HC Emissions

Hydro Carbon emission or the un-burnt Hydro Carbon emission is the expulsion of un-burnt fuel particles to the atmosphere from the combustion chamber of an engine through the exhaust. The primary reasons for such expulsions are the misfires in an engine and the Wall quenching. In-wall quenching the hot flame front advancing towards the wall is being quenched by the cold cylinder wall. The cylinder wall quenches off the flame front closer to the cylinder wall well before they are burnt completely.

The curves for HC emission from a single spark plug engine is as shown in Figure 12 initially, the HC emission will be high, and with the increase in speed, the HC emission decreases. The occurrence of initially Higher HC emissions is mainly due to the wall quenching process. At 2000 rpm using pure petrol E00, the HC emission was found to be 7242 ppm, and with E35, it was found to be 6595 ppm, with a percentage decrease of 10%.

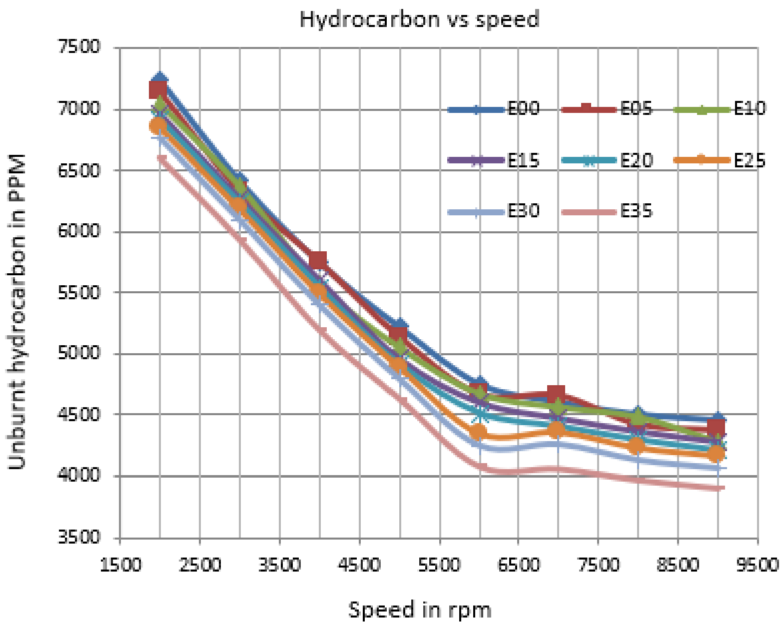

Fig. 12. Effect of the ethanol-gasoline blend on UBHC using Single Spark Plug

Similarly, the curves for HC emission from a twin spark ignition engine are as shown in Figure 13. The HC emission from twin spark ignition engine was found to be 6510 ppm at 2000 rpm using E00 fuel and 6160 ppm at 2000 rpm using E35 fuel amounting to a percentage difference of 5%The twin spark-ignition engine, in comparison with single spark ignition engine, showed a reduction in HC emission by 10% with E00 fuel and 7% with E35 fuel blend respectively.

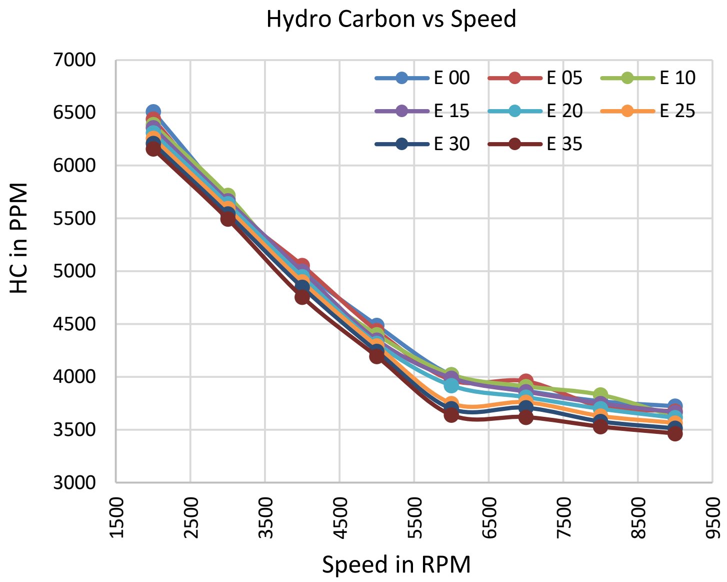

Fig. 13. Effect of the ethanol-gasoline blend on UBHC using Twin Spark Plug

4.7 Ethanol-Gasoline Blend's Effect on NOx Emissions

Higher pressures and higher cylinder temperatures are created during the combustion process. During this process, nitrogen quickly reacts with oxygen, and Oxides of nitrogen are formed, or the NOx is formed. The commonly formed Nitrogen oxide derivatives (NOx) are Nitric oxide (NO), Nitrous oxide (N_2O), Nitrogen dioxide (NO_2), etc. amongst all other nitrogen derivatives, the nitric oxide, and the nitrogen dioxide are much prominent.

The main reasons for the NOx formation are light throttle operation, lean air-fuel mixture, higher air intake temperature, excessive spark advance, and heated engine. Blending gasoline with ethanol results in an increase in octane number, increase in density, and latent heat of vaporization, but the calorific value of the fuel blend will be reduced. The curves of NOx under varying speeds, with a single spark plug, twin spark plug, and varying ethanol-gasoline blends, are shown in Figure 14 and Figure 15, respectively. It is seen that with increasing speed, the NOx increases, and from the maximum point, the curves take a downhill. With a single spark-ignition engine, the minimum NOx value of 673 mg/Nm^3 was found with E00 at 2000 rpm, and the maximum NOx value of 2075 mg/Nm^3 was found with E35. The value of NOx increases with an increasing percentage of ethanol because the presence of oxygen in the ethanol-gasoline blend will increase the ratio of oxygen to fuel in the combustion chamber where plentiful fuel is witnessed.

Nitrogen dioxide is a reddish-brown gas, which is corrosive and toxic. A large amount of NOx production is favored mostly during moderate loads and at heavy loads. Sometimes it is also created during cruising and light loads.

Another essential reason behind the increase in NOx value is the relative air-fuel ratio. With the increase in ethanol content, the air-fuel ratio steadily reaches the stoichiometric air-fuel ratio leading to complete combustion. The complete combustion tends to increase the cylinder temperature, and thereby, the formation of NOx is favored.

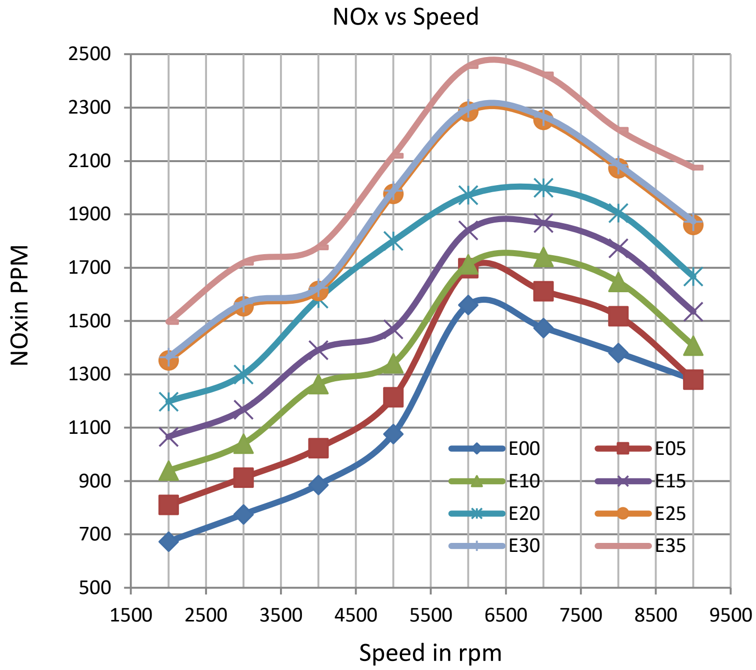

Fig. 14. Ethanol-gasoline blend's Effect on NOx emission using Single Spark Plug

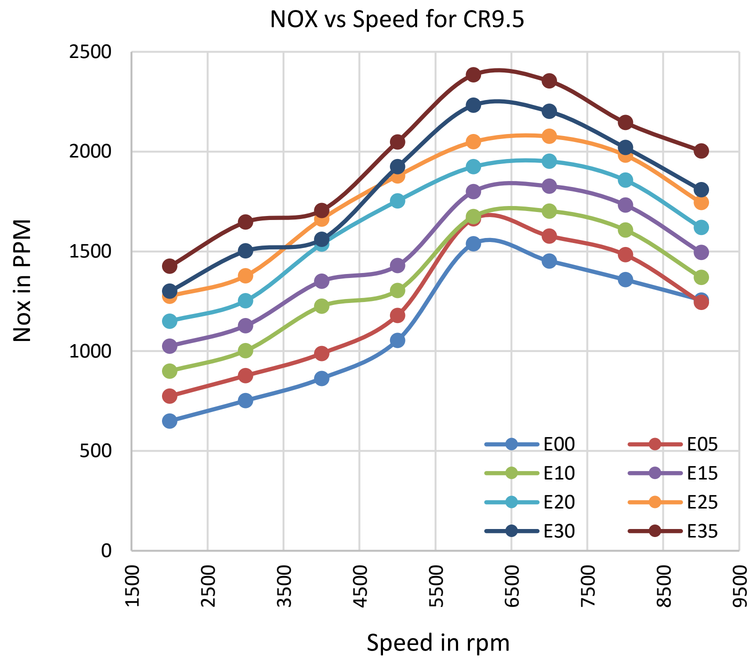

Fig. 15. Ethanol-gasoline blend's effect on NOx emission using twin Spark Plug

5. Conclusions

The popularity and demand for alternative fuels are increasing from day to day owing to limited fossil fuel reserves. The most promising alternative fuel to substitute liquid fossil fuels is the alcohol, especially the ethanol; it has its origin in renewable sources and therefore is inexhaustible, burns cleanly, and emits lesser emissions. By the use of ethanol in IC engines, the harmful emissions such as the HC and CO are limited to a considerable amount. The use of a twin spark plug reduces the amount of HC emission by aiding the complete combustion process. A summary of the observations made in the investigation is as listed below.

i. Torque produced by a twin spark ignition engine exceeds the value of torque produced by a single spark-ignition engine by 21% with an E35 blend
ii. By introducing an additional spark plug, the brake power of the engine was found to be increased by 12% as against that of the single spark-ignition engine. This is mainly due to the complete combustion of the fuel at higher rpm.
iii. The Brake Specific Fuel Consumption decreased by 6% with a twin spark ignition engine for all blends ranging from E00 to E35. With the percentage increase of ethanol in the blend and with an additional spark plug, the degree of fuel combusted in the same interval of time in a single spark plug engine is far less as compared against that of a dual spark plug engine. This forms the main reason behind the reduction of primary fuel consumption.
iv. Ethanol possesses a higher heat of evaporation than that of gasoline. As a result of this, the charge gets cooled, and its density increases, thus produce higher brake power as compared with pure petrol. With the reduction of temperature, the ethanol-gasoline blend that is admitted into the combustion chamber is also seen to increase. Thus a more significant amount of brake power is being produced with higher blends of Ethanol and gasoline as compared to that of regular petrol.
v. The twin spark-ignition engine, in comparison with a single spark ignition engine, showed a reduction in CO emission by 12% with E00 fuel and 3% with E35 fuel blend, respectively. With the percentage increase in addition of ethanol to gasoline, the number of hydroxyl groups that are readily available during combustion will also increase. Thus there is a reduction in the percentage of CO and an increase in the CO_2 percentage.
vi. In comparison with a single spark plug engine, the twin spark ignition engine produced an increase in the percentage of CO_2.indicating that with the addition of a second spark plug, the formation of aldehydes can be prevented. With the addition of a second spark plug, part of the charge which will not be combusted during the initial stages of combustion will be combusted, resulting in the reduction of regulated emissions from the exhaust of the engine.
vii. With the addition of ethanol, the physiochemical properties of the blend, such as the oxygen content, latent heat of vaporization, calorific value, favor the formation of NOx in the combustion chamber of the spark ignition (SI) engine. With the chances of the temperature getting increased the chances of NOx derivative formation also increases as the NOx formation takes place only at higher temperatures.

References

[1] Agarwal, Avinash Kumar. "Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines." *Progress in energy and combustion science* 33, no. 3 (2007): 233-271.
[2] Pikūnas, Alvydas, Saugirdas Pukalskas, and Juozas Grabys. "Influence of composition of gasoline-ethanol blends on parameters of internal combustion engines." *Journal of KONES Internal Combustion Engines* 10, no. 3-4, (2003).
[3] Balat, Mustafa, and Havva Balat. "Recent trends in global production and utilization of bio-ethanol fuel." *Applied energy* 86, no. 11 (2009): 2273-2282.

[4] Bayraktar, Hakan. "Experimental and theoretical investigation of using gasoline-ethanol blends in spark-ignition engines." *Renewable energy* , 30, no. 11 (2005): 1733-1747.

[5] Bergthorson, Jeffrey M., and Murray J. Thomson. "A review of the combustion and emissions properties of advanced transportation biofuels and their impact on existing and future engines." *Renewable and sustainable energy reviews* 42 (2015): 1393-1417.

[6] Argakiotis, C., Rakesh Mishra, Christopher Stubbs, and W. Weston. "The Effect of using an Ethanol blended fuel on Emissions in an SI Engine." *Renewable Energy and Power Quality Journal* 1, no. 12 (2014): 611-616.

[7] Wu, Chan-Wei, Rong-Horng Chen, Jen-Yung Pu, and Ta-Hui Lin. "The influence of air-fuel ratio on engine performance and pollutant emission of an SI engine using ethanol–gasoline-blended fuels." *Atmospheric Environment* 38, no. 40 (2004): 7093-7100.

[8] Celik, M. Bahattin. "Experimental determination of suitable ethanol-gasoline blend rate at high compression ratio for a gasoline engine." *Applied Thermal Engineering* 28, no. 5-6 (2008): 396-404.

[9] Costa, Rodrigo C., and José R. Sodré. "Hydrous ethanol vs. gasoline-ethanol blend: Engine performance and emissions." *Fuel* 89, no. 2 (2010): 287-293.

[10] Najafi, G., B. Ghobadian, T. Tavakoli, D. R. Buttsworth, T. F. Yusaf, and M. Faizollahnejad. "Performance and exhaust emissions of a gasoline engine with ethanol-blended gasoline fuels using artificial neural network." *Applied Energy* 86, no. 5 (2009): 630-639.

[11] Ganesan, V. *Internal combustion engines*. McGraw Hill Education (India) Pvt Ltd, 2012.

[12] Yücesu, Hüseyin Serdar, Tolga Topgül, Can Cinar, and Melih Okur. "Effect of ethanol-gasoline blends on engine performance and exhaust emissions in different compression ratios." *Applied thermal engineering* 26, no. 17-18 (2006): 2272-2278.

[13] Heywood, John B. "Internal combustion engine Jimdanentals." *McCtrw-Hill, New York* (1988).

[14] Liu, Shao-Hua, Li-Zhong Shen, Nian-Ye Ye, Yu-Hua Bi, and Xin Luo. "Research on the effects of E 10 hydrous ethanol-gasoline blend on performance and emissions of gasoline engine." *Neiranji Gongcheng(Chinese Internal Combustion Engine Engineering)* 33, no. 5 (2012): 46-51.

[15] Al-Hasan, M. "Effect of ethanol–unleaded gasoline blends on engine performance and exhaust emission." *energy conversion and management* 44, no. 9 (2003): 1547-1561.

[16] Manzetti, Sergio, and Otto Andersen. "A review of emission products from bioethanol and its blends with gasoline. Background for new guidelines for emission control." *Fuel* 140 (2015): 293-301.

[17] Srinivasan, C. Ananda, and C. G. Saravanan. "Study of combustion characteristics of an SI engine fuelled with ethanol and oxygenated fuel additives." *Journal of Sustainable Energy & Environment* 1 (2010): 85-91.

[18] Schifter, I., L. Diaz, J. P. Gómez, and U. Gonzalez. "Combustion characterization in a single-cylinder engine with mid-level hydrated ethanol-gasoline blended fuels." *Fuel* 103 (2013): 292-298.

[19] Suarez-Bertoa, R., A. A. Zardini, H. Keuken, and C. Astorga. "Impact of ethanol containing gasoline blends on emissions from a flex-fuel vehicle tested over the Worldwide Harmonized Light-duty Test Cycle (WLTC)." *Fuel* 143 (2015): 173-182.

[20] Venugopal, T., Ankit Sharma, Subhasish Satapathy, A. Ramesh, and M. K. Gajendra Babu. "Experimental study of hydrous ethanol-gasoline blend (E10) in a four-stroke port fuel injected spark ignition engine." *International Journal of Energy Research* 37, no. 6 (2013): 638-644.

[21] Yücesu, Hüseyin Serdar, Tolga Topgül, Can Cinar, and Melih Okur. "Effect of ethanol-gasoline blends on engine performance and exhaust emissions in different compression ratios." *Applied thermal engineering* 26, no. 17-18 (2006): 2272-2278.

[22] Ruzi, N. A., W. J. Yahya, H. Abd, and N. A. Mazlan. "Emission of Diesel Engine Running on Emulsion Fuel Made from Low-Grade Diesel Fuel." *Journal of Advanced Research in Materials Science* 15, no. 1 (2015): 1-8.