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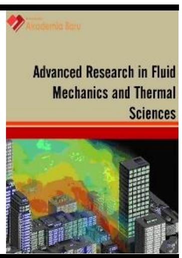

Investigation of Characteristics of Spark Ignition Engine Fuelled with Ethanol-Gasoline Blends Using Iso-octane Additive

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ABSTRACT

The quick depletion of petroleum reserves rises in automobile emissions, and an increase in costs and concerns for the environment has prompted a relentless quest to substitute fuels. For Gasoline, one of the best alternatives is found to be Ethyl Alcohol. As it is obtained from biomass crops enriched with starch, sugar, and cellulose material. These crops are renewable and pollution-free. The nature of ethyl alcohol is the same as compared to petrol. Both are liquid, and in this way, storage and transport are similar. Both can be blended expertly and burnt. In the present study, E30 (30% Ethanol + 70% Gasoline) blend was used and tests were carried out for a single-cylinder, 4-stroke, computerized spark-ignition (SI) gasoline engine fitted with eddy current dynamometer. Further, a precisely adjusted exhaust gas analyzer and the performance, combustion, and emission characteristics of the Spark Ignition Engine were recorded in “Enginesoft” software. In order to reduce the problem of knocking in the Spark Ignition Engine, along with E30 Blend, Iso-Octane additive, which is an excellent anti-knocking agent, was added in 0.3%, 0.4% and 0.5% by volume, i.e., E30+0.3, E30+0.4 and E30+0.5 respectively.

Keywords:
Ethanol; Gasoline; Iso-Octane; Performance; Combustion; Emission

1. Introduction

Increased utilization and unsteady rates of end costs of fuel bought us in various issues bringing in more attraction of alternative and low-price biofuel. Additionally, the natural use of petroleum-based fuels has driven us to a decrease in underground-based carbon resources. The quest for alternative fuels, which guarantees a harmonious connection with sustainable development, energy conservation, efficiency, and environmental preservation, has turned out to be exceptionally articulated in the present days [1]. Biofuels can give an available answer to this overall petroleum crisis. Also, petrol and diesel-driven automobiles are the primary sources of greenhouse gas emissions and acid rain. Researchers around the globe have investigated various substitutes and

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clean energy resources. Which can extinguish the regularly expanding energy thirst of today's population and reduce the emissions with higher utilization [2].

Ethyl Alcohol (C_2H_5OH) is the promising alternative biofuel which can substitute Gasoline, due to its various benefits. It is renewable, biodegradable, and produced from Biomass. It is having a high-octane rating than gasoline, higher laminar flame speed, high latent heat of vaporization, and contains oxygen content [3]. Ethanol is produced from biomass such as sugar, for example, sugarcane, biomass such as starch, for example, corn, biomass such as cellulose, for example, wood, which is renewable and produces very fewer emissions. Ethanol is comprised of a group of chemical compounds whose particles contain a hydroxyl group, OH, attached to a carbon molecule. Hence, the oxygen substance of this fuel supports the further combustion of gasoline. Also, ethanol is usually used to increase gasoline's octane number.

Knocking-in the Spark Ignition Engine occurs due to the pre-ignition of fuel. Knocking indicates the performance of the gasoline is inefficient. It reduces the power of the engine to a large level. The proportion of the ignition quality or flammability of petrol is called the Octane number (ON). Research Octane Number (RON) and Motor Octane Number (MON) are the two types of ON's. Higher the octane number, the lower will be the engine knocking. ON's can be increased either by carbon chain branching or by using gasoline octane boosters as additives. The different gasoline octane boosters were utilized as additives with gasoline. The gasoline is tetraethyl lead (TEL), methyl tertiary-butyl ether (MTBE), methylcyclopentadienyl manganese tricarbonyl (MMT), Iron pentacarbonyl, Toulene, Isooctane, and ferrocene. Aromatic alcohols, ethyl alcohol, and methyl alcohol also raise the ON of gasoline [4]. In the present study, Iso-octane is used as an additive with an E30 blend (30% Ethanol+70% Gasoline). Its octane number is 100, and It is a colorless, odorless liquid with a density of 690 kg/m3. It is added to E30 (30% ethanol + 70% gasoline) blend in various proportions of 0.3%, 0.4% and 0.5% by volume.

Lennox Siwale *et al.,* [5] used n-butanol as a fuel additive to methanol-gasoline blends and studied the impact on the combustion and emission properties on a single-cylinder spark-ignition engine. The mixes made were M10 (10% methanol; 90% gasoline by vol.), M10:20 (10% methanol, 20% n-butanol, 70% gasoline), M20:30 (20% methanol, 30% n-butanol, 50% gasoline) and M80:10 (80% methanol, 10% n-butanol, 10% gasoline). The outcomes indicated that the peak pressure increased with methanol fraction in the blend with gasoline. Unburned hydrocarbon emissions were reduced with M80 to 330 ppm and reduced. Further, with 10% n-butanol added to M80 and proved that n-butanol has the power of reducing unburned hydrocarbon emissions when methanol fraction is above 20% in petrol. Sai Vijay Venkatesh *et al.,* [6] studied the effect of using the octane boosters, namely toluene and ethanol, with gasoline on the emission and performance characteristics of a 4-cylinder, 4-stroke, Ambassador 1800 ISZ carbureted spark-ignition engine connected to eddy current dynamometer. The results obtained concluded that E20 T5 (Ethanol 20%, Toulene 5%, and Gasoline 75%) showed higher Brake Thermal efficiency and E20T5, E10T5 have higher CO and CO2 emissions compared to E10. But E20T5 and E10T5 showed lower HC and NOX emissions compared to E10. C. Anish Raman *et al.,* [8] studied the effects of using an oxygenated additive MTBE (Methyl Tertiary Butyl Ether) on the emission and performance qualities of a 4-cylinder 1817 cc engine by blending it with gasoline. The results showed that the addition of MTBE leads to an increase in Brake Thermal efficiency and Brake specific fuel consumption. There was a reduction in Carbon monoxide and Hydrocarbon emissions because of the complete combustion of fuel and the presence of O_2. M10 blend showed adequate combustion compared to pure gasoline.

C. Argakiotis *et al.,* [9] considered the effects of E0 and E30 Ethyl-alcohol gasoline blends on the working and emission aspects of a four-cylinder, four-stroke gasoline engine with a compression ratio referring to 9:1. The results indicated that the E30 combination increased the power and engine's torque. At full throttle condition, the E30 blend reduced CO emission, while the CO2 and NOX emission was increased. H S Farkade *et al.,* [11] used three different alcohols, mainly methyl alcohol, ethyl alcohol, and butanol, in a spark-ignition engine and studied the effects on engine emissions. M10, E10, and B20 among various blends showed the best results. The addition of oxygenates in gasoline improved combustion and reduced CO and HC emissions. Ashraf Elfasy [12] experimentally compared the effects of three different blended fuels. i.e., ethanol-methanol-gasoline (EM), n-butanol-isobutanol-gasoline (niB), and isobutanol-ethanol-gasoline (iBE) on the performance, combustion and emission characteristics to select the best alternative for gasoline from these three fuel blends. The tests were conducted at a low range of fuel blends (3-10% vol. in gasoline) with the engine speeds between 2600 rpm to 3400 rpm at the half throttle of a spark-ignition engine. The results showed that, among all blended fuels, EM fuel blends exhibited the best performance and lowest engine emissions. Nik Rosli Abdullah *et al.,* [13] checked the effects of using ethyl alcohol-gasoline mixture on engine performance and exhaust gas emissions. The tests were conducted on a single-cylinder, four-stroke engine with various blends of E10, E20, and E30 at a constant load of 2 N-m and varying speed range from 2000 rpm to 3000 rpm. The results concluded that the E20 blend gave the best Brake specific fuel consumption value of about 41.5% compared to gasoline. Ethanol gasoline blends improved the combustion process and resulted in lower exhaust temperature. Carbon monoxide emissions of the ethanol-gasoline mixture were reduced compared to gasoline. S.K. Kamboj *et al.,* [15] studied the effects of unleaded iso-octane, unleaded iso-octane-ethanol blend (E10), and iso-octane-methanol blend (M10) on the engine performance of a one-cylinder 4-stroke, gasoline engine. The results concluded that the E10 mix is the most suitable blend for spark ignition engines as it gives better performance at medium speed and medium loads.

From the above literature review, adding oxygenates such as ethanol, methanol, MTBE produces very few emissions when they are burnt and are cleaner fuels. Also, they increase the performance of the spark-ignition engine by increasing its efficiency. In order to boost the octane degree of Gasoline fuel, various additives have been used and tested to investigate the effect of these supplements on the working, combustion, and emission attributes of the petrol engine. In the present investigation, we have considered the Iso-octane additive as a gasoline octane booster. Along with adding 30% ethanol with gasoline, we have further added Iso-octane additive in 0.3%, 0.4%, and 0.5% by volume. i.e. E30+0.3, E30+0.4 and E30+0.5. These three blends were tested on a one-cylinder, 4-stroke spark-ignition engine fitted along with an eddy current dynamometer and a precisely adjusted exhaust gas analyzer. In the first case, tests were conducted at maximum load, the maximum compression ratio of 10:1, and at a varying engine speed range of 1200 rpm to 1800 rpm. In the second case, tests were conducted at maximum load, maximum engine speed of 1800 rpm, and a variable compression ratio of 8:1 to 10:1. The results obtained were recorded in “Engine Soft” Software. The present study proves that a limited supply of Iso Octane promoters has been used as efficient and active antiknock additives in a normal engine without any modifications. Also, it increases the performance of the spark-ignition engine and reduces the engine emissions when added with E30 (30% Ethanol and 70% Gasoline) blend.

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, and 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: Mustafa Kemal, 2018 [7], Kheiralla, 2011 [10]

3. Methodology

The tests have been conducted on a four-stroke, single-cylinder, computerized spark-ignition gasoline engine running under constant load, maximum compression ratio, and variable speeds in the first case. In the second case, the engine was made to run under constant load, maximum speed, and variable compression ratio. Table 2 illustrates the specifications of the engine.

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

Figure 1 shows the experimental setup with an exhaust gas analyzer and 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 [14].

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

Gasoline (E5), which contents 5% ethanol, was purchased from a nearby Gasoline pump and was blended with ethanol to prepare three 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 form the following blends. These are E30+0.3 (30% Ethanol + 70% gasoline + 0.3% Isooctane), E30+0.4 (30% Ethanol + 70% gasoline + 0.4% Isooctane) and E30+0.5 (30% Ethanol + 70% gasoline + 0.5% Isooctane). Guarantee cooling water flows for eddy current dynamometer, calorimeter, piezo-sensor, and engine cooling. Begin the setup and run the engine at the no-load condition for 5-6 minutes. Switch on the PC and run "Engine soft." Step by step increment throttle to full open condition and load the engine all the while keeping up engine speed at 1800 RPM. Wait for steady-state (for 5 min) and input the information in the "Engines of." 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 E30+0.3, E30+0.4, and E30+0.5 blends. The compression ratio is kept maximum at 10:1. After the engine achieved the settled working condition, engine emission parameters. For example, CO, HC, CO2, and NOX and the Exhaust gas temperature from a precisely adjusted Exhaust gas analyzer were recorded. In the second phase of examinations, the engine speed was kept constant at 1800 rpm, and the Compression ratio differed from 8:1 to 10:1. The load was likewise kept constant in both cases. The outcomes and performance plots were seen in Engines soft" [16-19].

4. Results and Discussions

4.1 Performance of S.I Engine Fuelled with E30+0.3, E30+0.4, and E30+0.5 Blends

Figure 2 shows the behavior of Brake specific fuel consumption. From the graph, it can be observed that, as the engine speed is increased, there is a decrease in BSFC. Therefore, the maximum reduction is found at about 0.28 kg/kW-hr at a speed of 1800 rpm for the E30+0.5 blend. The BSFC tends to reduce with the increase in addition to Iso-octane under the E30 mixture. It is noted that the brake-specific fuel consumption (BSFC) at 1800 rpm using E30+0.3, E30+0.4, and E30+0.5 is decreased by 2.7%, 5.55%, and 22.22%, respectively in comparison with E30.

Figure 3 shows the behavior of Brake specific fuel consumption with a variable Compression ratio at a maximum engine speed of 1800 rpm along with a maximum load of 6 kg. From the graph, it can be observed that the BSFC decreases with the increase in the compression ratio. It was found that the BSFC decreases with the increase in iso-octane additive in E30. It was observed that the BSFC at a compression ratio of 10:1 using E30+0.3, E30+0.4, and E30+0.5 blend was decreased by 15.09%, 20.75%, and 16.98% respectively compared to E30.

Figure 2 and 3 found that an increase besides isooctane will results in excellent efficiency in performances. Hence, the isooctane is useful in fuel consumption with their effects, and it is possible the used for the increases in BSFC performance. Whereas, for the compression ratio, it is slightly higher at the minimum range. When the compression ratio increases, it gives a compelling performance due to its chemical combination of isooctane.

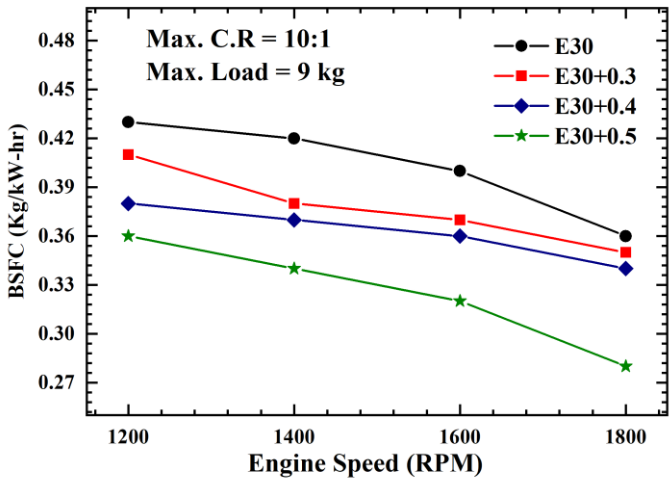

Fig. 2. Variation of BSFC with engine speed

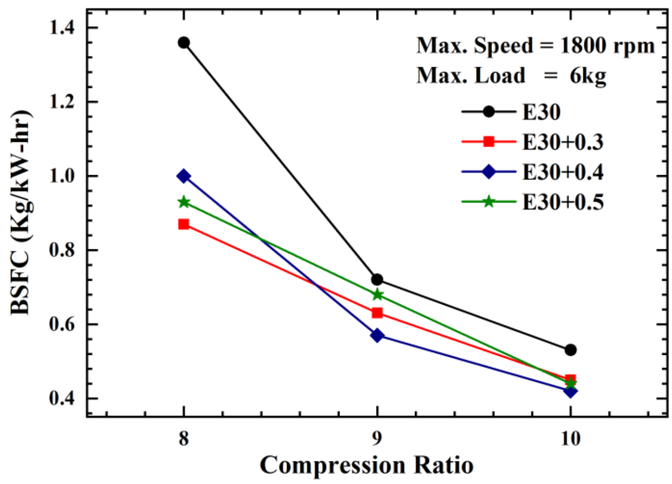

Fig. 3. Compression Ratio for E30 blend added with Iso-Octane additive

Figure 4 shows the behavior of Brake thermal efficiency (BTE) with increasing Engine speed. From the graph, it can be detected that the BTE increases with the increase in engine speed and reaches a maximum at a speed of 1800 rpm. The BTE increases with the increase in isooctane percentage in E30. E30+0.5 shows a maximum BTE of 23.83%. It was witnessed that the BTE at 1800 rpm using E30+0.3, E30+0.4, and E30+0.5 were increased by 7.40%, 21.38%, and 25.22% respectively compared to E30. Figure 5 illustrates the behavior of BTE with a variable Compression ratio at a maximum engine speed of 1800 rpm along with a maximum load of 6 kg. From the graph, it can be witnessed that the BTE increases with the increase in the compression ratio and reaches a maximum of 26.23% at a C.R of 10:1. It was witnessed that the BTE at a C.R of 10:1 using E30+0.3, E30+0.4, and E30+0.5 was increased by 2.66%, 6.04%, and 10.72% respectively compared to E30.

After finding the BSFC, it is interesting to see the performance of BTE. Indeed, the BTE is high for the case of engine speed and compression ratio (Figure 4 and 5). This is due to the increase in temperature with an increase in speed. Hence it reaches a higher level with the effect of isooctane temperature effects. It shows the BTE is varying at a lower level with the absence of isooctane. Whereas with isooctane at a higher level. This gives a slight sign that adding the isooctane will increase BTE.

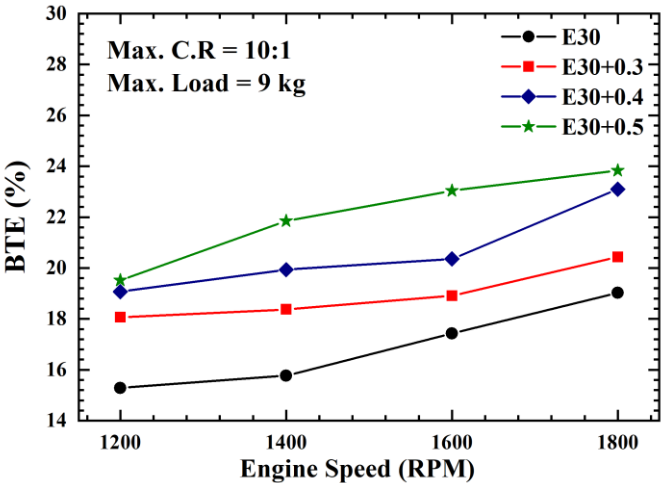

Fig. 4. Variation of BTE with engine speed

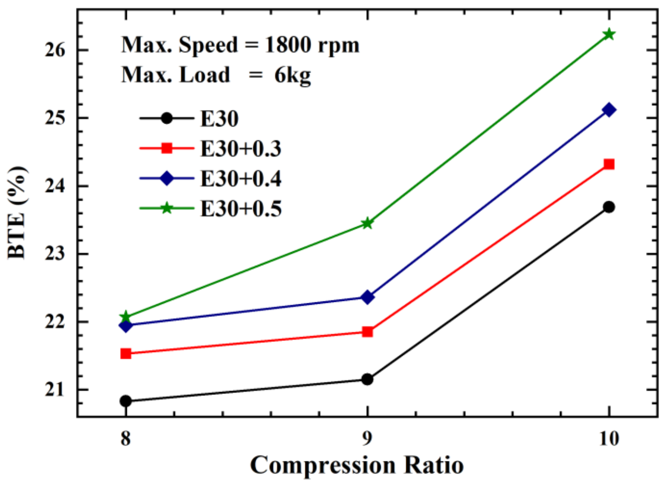

Fig. 5. Compression Ratio for E30 blend added with Iso-Octane additive

4.2 Combustion Characteristics of S.I Engine Fuelled with E30+0.3, E30+0.4, and E30+0.5 Blends

Figure 6 shows the variation of Cylinder pressure proportionate to crank angle for three diverse fuel mixtures (E30+0.3, E30+0.4, and E30+0.5) with varying engine speed. From the graph, it can be observed that the E30+0.5 blend has a maximum cylinder pressure of about 20.97 bar compared to E30+0.3 and E30+0.4, which is having 15.48 bar and 18.98 bar respectively. The higher cylinder pressure is accomplished as a result of more oxygen accessible in the chemical configuration, which enhances combustion efficiency.

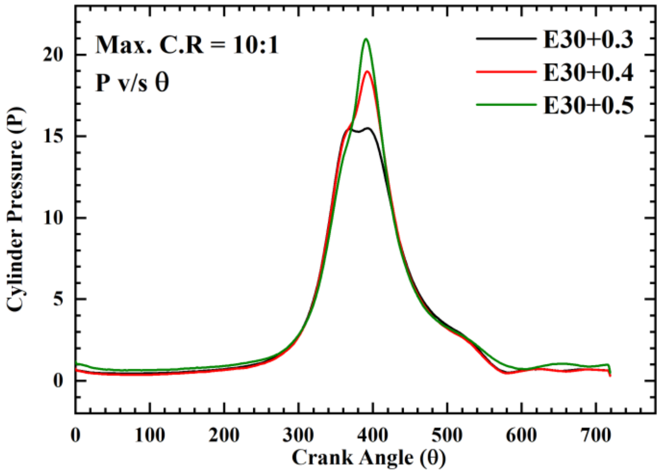

Fig. 6. Cylinder pressure vs. Crank angle for E30 blend added with Iso-Octane additive

Figure 7 indicates the variation of cumulative heat release proportionate to crank angle for three diverse fuel mixtures (E30+0.3, E30+0.4, and E30+0.5) with varying engine speed at a maximum compression ratio of 10:1. From the graph, it can be witnessed that, E30+0.4 and E30+0.5 blend have a higher cumulative heat release of about 1.06 kJ compared to E30+0.3, which is having 1.03 kJ. Figure 8 shows the variation of net heat release proportionate to the crank angle for three diverse fuel mixtures (E30+0.3, E30+0.4, and E30+0.5) with varying engine speeds at a maximum compression ratio of 10:1. From the diagram, it can be observed that the E30+0.5 blend has a higher net heat release of about 26.76 J/deg compared to E30+0.3 and E30+0.4, which is having 19.75 and 23.95 J/deg.

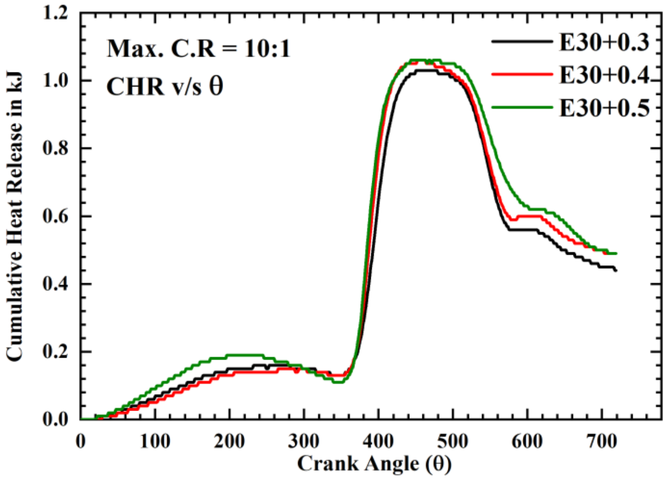

Fig. 7. Variation of Cumulative heat release vs. Crank

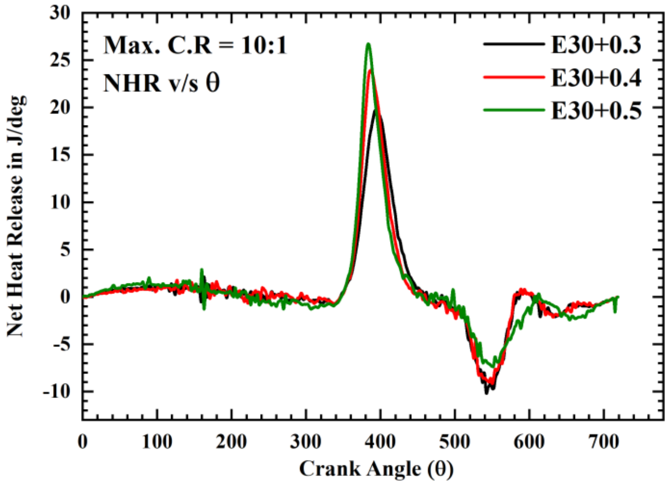

Fig. 8. Net heat release vs. Crank angle for E30 blend added with Iso-Octane additive

4.3 Emission Characteristics of S.I Engine Fuelled with E30+0.3, E30+0.4, and E30+0.5 Blends

Figure 9 illustrates the concentration of CO emission for varying Engine speeds. From the graph, it can be concluded that the CO emission reduces with the increase in engine speed, and the maximum reduction was 0.029% obtained at 1800 rpm for the E30+0.5 blend. The reduction in CO emission was due to the addition of iso-octane additive in the E30 blend. The CO concentration at 1800 rpm using E30+0.3, E30+0.4 and E30+0.5 was decreased by 7.5%, 17.5% and 27.49% respectively compared to E30. Figure 10 shows the concentration of CO emission for different Compression ratios at a maximum engine speed of 1800 rpm and a maximum load of 6 kg. From the graph, the CO emission is maximum at the compression ratio of 9:1, whereas reduction in CO emission was found at the compression ratio of 10:1 for all the blends. E30+0.5 shows a maximum reduction of 0.045% at a C.R of 10:1. The CO concentration at a C.R of 10:1 using E30+0.3, E30+0.4 and E30+0.5 was decreased by 15.29%, 32.94%, and 47.06% respectively compared to E30. This study shows that the addition of isooctane will result in reducing the concentration of CO emission concerning engine speed and compression ratio (Figure 9 and 10). This is due to isooctane chemical combination effects with the presence of methyl at different substitution positions such as 2 and 4.

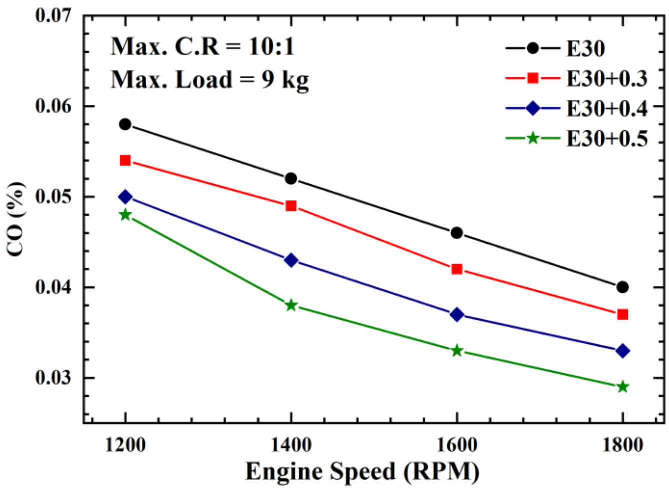

Fig. 9. Variation of CO with engine speed

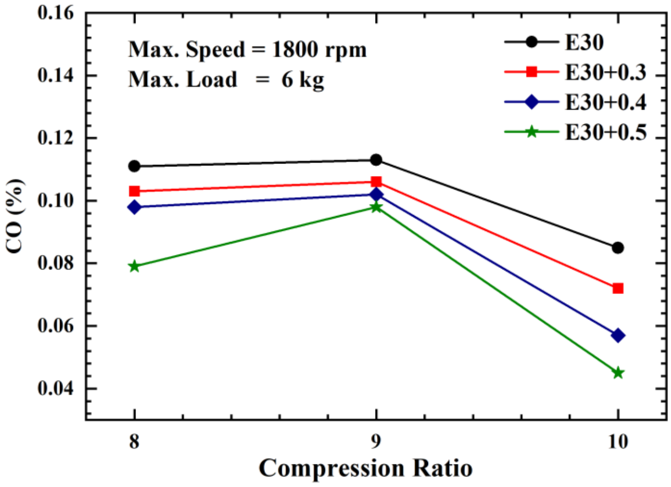

Fig. 10. Compression Ratio for E30 blend added with Iso-Octane additive

Figure 11 illustrates the concentration of HC emission for different Engine speeds. From the graph, it can be concluded that the HC emission reduces with the increase in engine speed, and the maximum reduction was 98 ppm obtained at 1800 rpm for E30+0.5 blend. The decrease in HC emission was due to the addition of iso-octane additive in the E30 combination. Figure 12 demonstrates the concentration of HC emission for different Compression ratios at a maximum engine speed of 1800 rpm and a maximum load of 6 kg. From the graph HC emission decreases with the increase in C.R and the maximum reduction was found at a compression ratio of 10:1 for all the blends. E30+0.5 shows the least HC emission of 98 ppm. This is due to the increase in iso-octane additive in the E30 blend. The HC concentration at a C.R of 10:1 using E30+0.3, E30+0.4 and E30+0.5 was decreased by 3.48%, 7.82%, and 14.78% respectively compared to E30. As per the Figure 11 and 12 concentration of HC emission is similar to the CO as specified. The chemical composition of isooctane is effective in reducing the concentration.

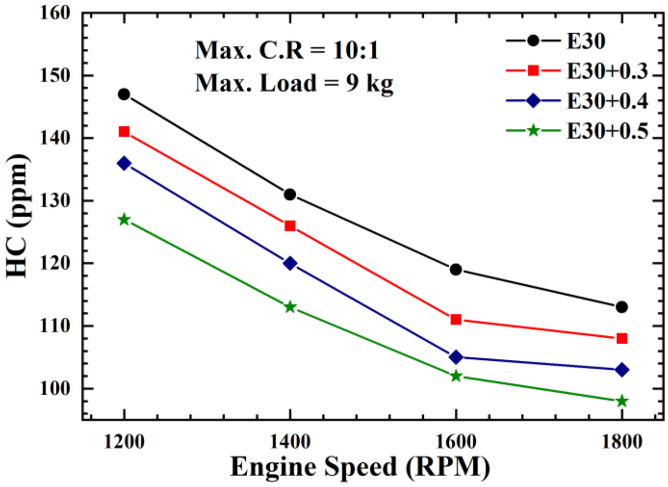

Fig. 11. Variation of HC with engine speed

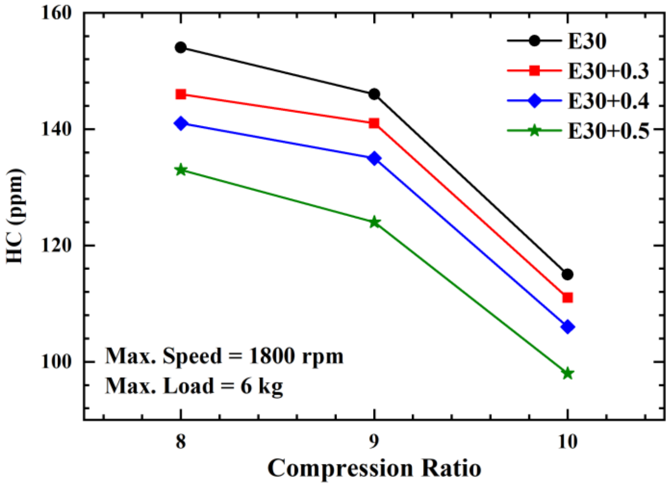

Fig. 12. Compression Ratio for E30 blend added with Iso-octane additive

Figure 13 illustrates the concentration of CO2 emission for varying Engine speeds. From the graph, the CO2 level increases with the increase in engine speed and reaches a maximum of 5.35% at 1800 rpm for the E30+0.5 blend. The addition of iso-octane additive in the E30 mixture increases the CO2 emission indicating that complete combustion is taking place with an increase in iso-octane in the E30 blend. Figure 14 shows the concentration of CO2 radiation for different Compression ratios at a maximum engine speed of 1800 rpm and a maximum load of 6 kg. From the graph, it can be seen that the CO2 emission increases at a compression ratio of 9:1, whereas it decreases at a compression ratio of 8:1 and 10:1. The CO2 concentration at a compression ratio of 9:1 using E30+0.3, E30+0.4, and E30+0.5 blends was increased by 1.03%, 4.98%, and 7.47% respectively compared to E30. The presence of oxygen substitution of 2 will affect opposite to CO and HC and increase the performance of CO2 with respect to engine speed and compression ratio (Figure 13 and 14).

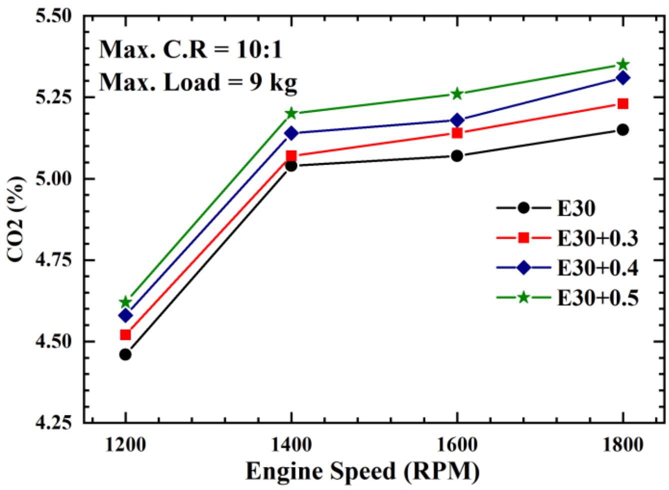

Fig. 13. Variation of CO2 with engine speed

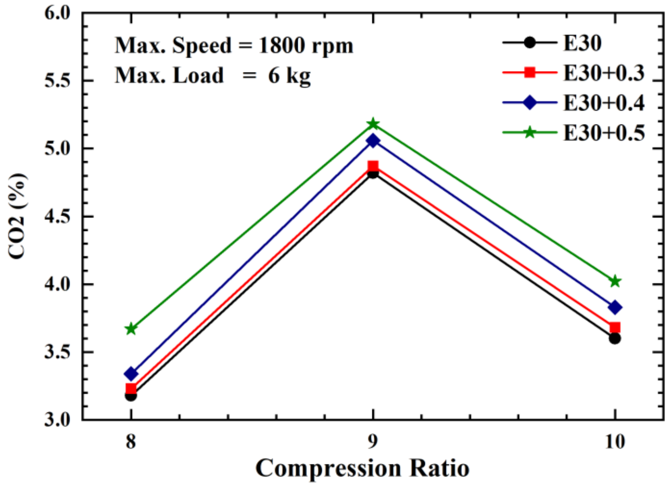

Fig. 14. Compression Ratio for E30 blend added with Iso-Octane additive

5. Conclusion

Engine performance parameters such as Brake specific fuel consumption reduces with the increase in engine speed, whereas the Brake thermal efficiency increases. Among all the combinations, the E30 + 0.5 blend gave maximum brake thermal efficiency of 23.83% at a maximum engine speed of 1800 rpm. Concentration CO and HC emissions decrease dramatically by ethanol addition due to the lean burning of the fuel. The maximum CO reduction was 0.029% obtained at 1800 rpm for the E30+0.5 blend. The maximum HC reduction was 98 ppm obtained at 1800 rpm for the E30+0.5 mixture. The CO_2 emission expanded as a result of the enhanced and complete burning of the fuel due to the secondary oxygen supplied by ethyl alcohol. The combustion mechanism was found to be improved inside the engine cylinder. The addition of ethanol to gasoline resulted in leaner better combustion, whereas the addition of isooctane additive into the ethanol-gasoline blend (E30) reduced engine knocking by increasing the octane rating of the blend. The maximum cylinder pressure was 20.97 bar during the power stroke for the E30+0.5 combination. Ethanol is the best alternative, clean and renewable fuel that can be blended with gasoline effectively. Hence, the Spark Ignition engine can run on E30 Blend with small amounts of octane booster like Iso octane without any alteration to the engine design and fuel system. Finally, the gasoline engine performs satisfactorily on the E30 blend added with small amounts of isooctane additive without any modification to the engine.

References

[1] Joshi, Sandeep M., Raahul Krishna, Balagouda A. Patil, and Aneesh C. Gangal. "Performance Evaluation of Petrol-Ethanol Blends and Testing on Multicylinder 4-Stroke SI Engine." *Journal of Alternate Energy Sources and Technologies* (2015): 41-45.

[2] El-Faroug, Musaab O., Fuwu Yan, Maji Luo, and Richard Fiifi Turkson. "Spark ignition engine combustion, performance and emission products from hydrous ethanol and its blends with gasoline." *Energies* 9, no. 12 (2016): 984.

[3] Gravalos, Ioannis, Dimitrios Moshou, Theodoros Gialamas, Panagiotis Xyradakis, Dimitrios Kateris, and Zisis Tsiropoulos. "Performance and emission characteristics of spark ignition engine fuelled with ethanol and methanol gasoline blended fuels." *Alternative fuel* 85 (2011).

[4] Demirbas, Ayhan, M. A. Balubaid, A. M. Basahel, W. Ahmad, and M. H. Sheikh. "Octane rating of gasoline and octane booster additives." *Petroleum Science and Technology* 33, no. 11 (2015): 1190-1197.

[5] Siwale, L., and A. Bereczky. "Effect of n-butanol fuel additive to methanol-gasoline blend on combustion and emission characteristics in a single cylinder spark ignition engine." *International Journal of Petrochemical Science & Engineering* 3, no. 3 (2018).

[6] Venkatesh, Sai Vijay, and R. Udayakumar. "Performance and emissions of si engine with octane boosters." In *MATEC Web of Conferences*, vol. 249, p. 03008. EDP Sciences, 2018.

[7] Balki, Mustafa Kemal, Volkan Cavus, İsmail Umut Duran, Resul Tuna, and Cenk Sayin. "Experimental study and prediction of performance and emission in an SI engine using alternative fuel with artificial neural network." *International Journal of Automotive Engineering and Technologies* 7, no. 1 (2018): 58-64.

[8] AnishRaman, C., K. Varatharajan, P. Abinesh, and N. Venkatachalapathi. "Analysis of MTBE as an Oxygenate Additive to Gasoline." *Int J Eng Res Appl* 4 (2014): 712-718.

[9] 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* 12 (2014).

[10] Kheiralla, A. F., Mohamed El-Awad, Mathani Y. Hassan, M. A. Hussen, and Hind I. Osman. "Effect of ethanol-gasoline blends on fuel properties characteristics of spark ignition engines." *University Of Khartoum Engineering Journal* 1, no. 2 (2011).

[11] Farkade, H. S., and A. P. Pathre. "Experimental investigation of methanol, ethanol and butanol blends with gasoline on SI engine." *International Journal of Emerging Technology and Advanced Engineering* 2, no. 4 (2012): 205-215.

[12] Elfasakhany, Ashraf. "Performance and emissions of spark-ignition engine using ethanol–methanol–gasoline, n-butanol–iso-butanol–gasoline and iso-butanol–ethanol–gasoline blends: a comparative study." *Engineering science and technology, an international journal* 19, no. 4 (2016): 2053-2059.

[13] Abdullah, Nik Rosli, M. S. M. Zaharin, A. M. I. Mamat, M. R. M. Nawi, and Hazim Sharudin. "Effects of ethanol blends on gasoline engine performance and exhaust emissions." *Jurnal Teknologi* 76, no. 11 (2015): 107-112.

[14] Elfasakhany, A. "The effects of ethanol-gasoline blends on performance and exhaust emission characteristics of spark ignition engines." *International Journal of Automotive Engineering* 4, no. 1 (2014): 609-620.

[15] Kamboj, S. K., and M. N. Karimi. "An experimental investigation of spark ignition Engine fueled with ethanol/iso-octane and methanol/iso-octane fuel blends." (2013): 368-378.

[16] NA Ruzi, WJ Yahya, HA Kadir, NA 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.

[17] Ja'afar, Mohammad Nazri Mohd, Anis Athirah Mohd Azli, Muhammad Amirul Faiz Mohd Azman, and Mazlan Said. "Combustion performance of firing biodiesel from waste cooking oil in an oil burner." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 47, no. 1 (2018): 45–55.

[18] Afzal, Asif, Mohammed Kareemullah, and Abdul Razak RK. "Production of biodiesel from various sources and comparative engine perfor-mance studies by using different biodiesel blends." *Journal of Engg. Research* 6, no. 4 (2018): 1-21.

[19] Sreenath, Jishnu, and Anand Pai. "Biodiesel: a review on next generation fuels." *Journal of Advance Research in Fluid Mechanics Thermal Sciences* 43, no. 1 (2018): 58-66.