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ORIGINAL CONTRIBUTION

Effect of Iso-Butanol Blends in Spark Ignition Engine as an Alternative

Balaji Dhanapal[1] · T. Mathevan Pillai[1] · B. Chellappa[1] · Ravishankar Sathyamurthy[2]

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Abstract The article presented is concerned with studying the effect of ethanol, and iso-butanol concentrations in a spark ignited, single-cylinder four-stroke engine on the engine parameters such as performance, combustion, and emission. The engine performance characteristics such as specific fuel consumption, brake thermal efficiency, and in-cylinder pressure were examined for different engine's operational loads. Similarly, the emission parameters such as CO, HC, and NOx were analyzed. Results showed that the influence of iso-butanol and ethanol improved the thermal by 6% than that of petrol. As a result of adding iso-butanol and ethanol with petrol, fuel consumption reduction can be observed. The CO, NOx, and HC emission were noted as 1.25% by vol, 146 ppm, and 175 ppm, respectively, whereas the CO2 is noted as 7.7% for 5% ethanol and 15% Iso-butanol. The optimum concentration of iso-butanol and ethanol was found as 15 and 5%, respectively, which improved the engine operating parameters and decreased the emission produced. The emission such as CO, Nox, and HC shows a significant reduction; on the other hand, the CO2 showed a drastic rise for the optimized blend proving the progression of complete combustion

Keywords Emission · Ethanol · Efficiency · Ethanol · In-cylinder parameters

✉ Ravishankar Sathyamurthy
raviannauniv23@gmail.com

1 Department of Mechanical Engineering, Hindustan Institute of Technology and Science, Chennai 603103, Tamil Nadu, India

2 Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Arasur, Coimbatore 641407, Tamil Nadu, India

Abbreviations

CO_2	Carbon dioxide
CO	Carbon monoxide
NOx	Nitrogen oxide
HC	Hydro carbons
SFC	Specific fuel consumption
BTE	Brake thermal efficiency
P85 + E5 + B10	85% Petrol + 5% Ethanol + 10% Iso-butonal
P82.5 + E5 + B12.5	82.5% Petrol + 5% Ethanol + 12.5% Iso-butonal
P80 + E5 + B15	80% Petrol + 5% Ethanol + 15% Iso-butonal
SI	Spark ignition
IC	Internal combustion
CA	Crank angle

Introduction

Every scientist's dream is to find an alternative energy source that can be used for future mobility by producing a small amount of emissions and improved automobile engine efficiency. Combustion of fossil fuel and automobile exhaust are the major sources of air pollution in the atmosphere [1–4]. The government set forth several regulatory laws to reduce the emission from automobile and industrial exhaust. The serious issue that modern society faces is the prominent increase in the automobile engine's environmental emission. An equal amount of emissions was emitted into the atmosphere from automobile working under the principle of spark ignition and compression ignition. The primary kind of emissions produced was the formation of NOx, CO, and HC, whereas the secondary kind includes ozone. A series of reactions occurs in the atmosphere, leading to serious health issues and environmental issues while emitting these pollutants [5]. There are serious health issues that arise with the continuous emission exhaustion. Apart from these issues, environmental effects such as respiratory, odors, smog, global warming, and acid rain are the other related problems with the emission produced. To replace conventional fuel, several alternative fuels were researched by many researchers. Under normal atmospheric conditions, pollutants emitted into the atmosphere will affect the balance of nature and the environment. A considerable amount of carbon dioxide is emitted into the atmosphere, which is recycled by the natural cycle by converting CO2 to oxygen within a confined area. If the level of CO2 emission exceeds 5000 ppm, then there is a serious potential health hazard. The primary cause of emission produced from automobile engines is the dissociation of nitrogen, quality of fuel and air used, and non-stoichiometric combustion. The country's economic growth depends on the transportation sector, and all the automobiles were equipped with IC engines. With the present technological development, the primary exhaust emissions produced are SO2, NOx, CO, soot, smoke, and HC reduced with improved performance by adding additive and fuel [6–10]. Fuels currently used in automobiles are added with additives that improve the engine's life and augmented efficiency. The addition of a small amount of additive with the fuel has greater effects on the engine's emission and performance. The refineries and the end-users are making the fuel with higher performance and reduced emission, the additives are added. Due to higher toxicity contents with barium compounds, metallic additives are not used by the refineries. Even though the research interest is revised, the possibility of fuel with additives on reduced emission level is verified. Automobile engines are fuelled using alcohol from the nineteenth century, while its usage was limited due to its higher price. The use of alcohol as a fuel additive provides excellent antiknock characteristics by the gasoline fuel and reduced emissions such as HC and CO. The production of alcohol and its potential was studied by Houghton-Alico [11]. Fuel additives that are used in automobiles are ethanol, methyl tertiary butyl ether, tertiary butyl alcohol, and methanol. There are several advantages in using alcohol fuel in the engine, but it is not used extensively in engines due to economic, technology, and regional consideration. While considering the environmental impact, ethanol can be used as an alternative energy source as it can be fermented and distilled from various biomass as feedstock. Due to lower toxicity and renewability, ethanol can be blended with gasoline, and it is better than methanol. Various researchers have carried out extensive research work to reduce the emission and augment the SI engine's performance. The use of ethanol as an additive in petrol fuel was carried out by El-Kassaby [12], Winnington and Siddique [13], and Hamdan & Jubran [14]. Many of the researchers have limited the concentration of ethanol to 15% with petrol fuel. Palmer [15] tested the SI engine using oxygenated gasoline. Taljaard et al. [16] performed experiments in an SI engine fuelled using oxygenated fuel to assess the engine performance and exhaust emission.

From the various literature studied, it was found that economic and environmental considerations were to be considered, so in the present study, an attempt is made to analyze the effect of adding a constant concentration of ethanol and varied concentration of iso-butanol petrol fuel. The prepared fuel is tested in a spark-ignition petrol engine to performance and emission characteristics. Iso-butanol additive is added in a concentration of 10, 12.5, and 15%, whereas ethanol additive is added in a constant concentration of 5%. Engine load is varied, while the speed of the engine is kept constant. A detailed comparison of the obtained engine performance and emission parameters was made with the engine fuelled using prepared fuel and petrol fuel.

Experimental Setup and Method

A single-cylinder air-cooled four-stroke spark ignition engine with a capacity of 100 cc is used in the present investigation. An eddy current dynamometer is used to load the engine. The detailed specification of the engine used is tabulated in Table. 1. Figure 1 shows the detailed schematic diagram of the experimental setup used. The engine is equipped with a tachometer, torque gauges, and switched to load the engine. A calibrated burette is used to measure the amount of fuel consumed. The fall of fuel in the burette is measured using a stopwatch. In the present study, a Sun glass Analyser MGA 1200 is used to measure the engine's emission after the combustion.

Initially, the engine was allowed to run for at least 20–30 min to warm up. To achieve the maximum power delivered from the engine, the air–fuel ratio is adjusted. The entire experiments were carried out in the test engine at a constant speed with throttle opening position at 3/4 and varied engine torque. The speed of the engine is measured using an RPM counter. The engine is allowed to cool for a period of time before a new blend is used. Also, the engine fuelled using new blends is allowed to run for a period of time to attain thermal equilibrium. A minimum of 5 experiments were conducted for each fuel blend, and the average value is taken. Parameters such as torque, speed, and amount of fuel consumed are constantly measured. Similarly, emissions such as HC, NOx, CO, and CO2 are

Table 1 Detailed specification of the engine

Stroke × Bore	90 × 70 mm
Engine make and model	Bajaj engine
Compression ratio	7.4:1
Cubic capacity	100 cc
Fuel	Petrol
Rated power	5.2 kW @ 6500 rpm
Engine type	Four-stroke, single-cylinder air-cooled engine

measured using an exhaust gas analyzer. The engine performance parameters such as brake thermal, fuel consumption, and volumetric efficiency are estimated using standard correlation. Similarly, the specification of the engine is tabulated in Table 1 and Table 2 shows the specification of the exhaust gas analyzer. The range and accuracy of the exhaust gas analyzer is tabulated in Table 2. Errors usually happen in the measurement during the experiments. Due to poor calibration, logical errors occur. Normally, uncertainty analysis is carried out by taking the readings 3–4 times with the standard deviations from the measured values. The uncertainty of the experiment is calculated using standard equation (Eq. 1). Overall uncertainty from the emission is found as 1.11%, while the experiment overall uncertainty is found as 1.75%.

Table 2 Specification of exhaust gas analyzer

Emission	Range	Accuracy
CO (% Vol)	0–10	0.01
HC (ppm)	0–20,000	1
CO_2 (% Vol)	0–20	0.01
NOx (ppm)	0–2000	0.5

$$\text{Overall uncertainty} = \sqrt{\mathrm{HC}^2 + \mathrm{CO}^2 + \mathrm{CO}_2^2 + \mathrm{NO}_x^2 + \mathrm{BTE}^2 + \mathrm{BSFC}^2} \quad (1)$$

$$\text{Uncertainty from emission} = \sqrt{\mathrm{HC}^2 + \mathrm{CO} + \mathrm{CO}_2^2 + \mathrm{NO}_x^2} \quad (2)$$

The brake thermal efficiency of the engine is estimated using Eq. (3) and as follows,

$$\mathrm{BTE} = \frac{1}{\mathrm{BSFC} \times \text{Calorific value}} \times 3600 \times 100\% \quad (3)$$

Brake specific fuel is calculated using Eq. (4),

$$\mathrm{BSFC} = \frac{\mathrm{TFC}}{\mathrm{BP}} (\mathrm{kg/kW - hr}) \quad (4)$$

The total fuel consumption is calculated using Eq. (5),

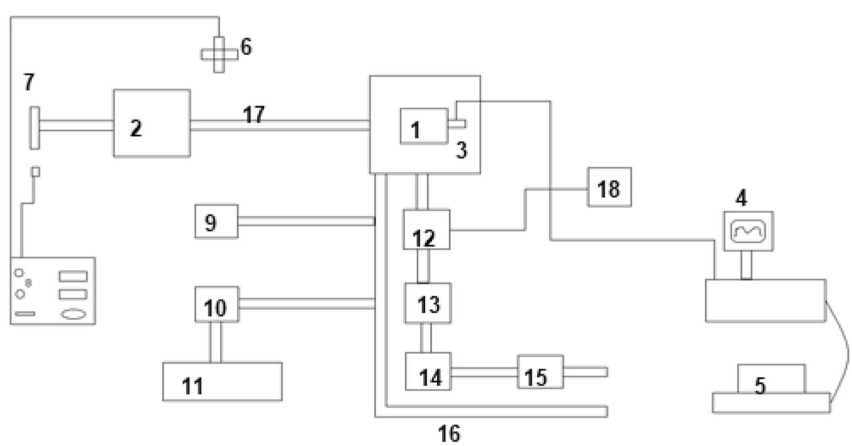

Fig. 1 Experimental setup

1. Engine
2. Eddy current dynamometer
3. Electric pressure pickup
4. Personal computer
5. Printer
6. Load sensor
7. RPM Counter
8. Dynamometer control Panel
9. Exhaust gas temperature
10. Moisture separator
11. Exhaust gas analyzer
12. Carburetor
13. Air filter
14. Air box
15. Orifice meter
16. Exhaust pipe
17. Shaft
18. Fuel measuring unit

$$\text{TFC} = \frac{\text{Volume of fuel consumed} \times 3600 \times \text{Specific gravity}}{t \times 1000} \text{ (kg/hr)} \quad (5)$$

Result and Discussion

This section deals with the SI engine's major results by adding different concentrations of iso-butanol and constant ethanol concentration with petrol fuel by keeping the throttle at 3/4th opening, and the engine performance and emission were discussed in detail.

Performance Analysis

Fuel Consumption

Fuel consumption on varied engine torque using blended fuel and petrol in SI engine is plotted in Fig. 2. It can be seen that fuel consumption using blended fuel is lower compared to that of petrol fuel, and it is noted that on increasing engine torque, the fuel consumption increases. The decrease in fuel consumption is due to the lower heating value of the fuel exhibited in addition to iso-butanol and ethanol additive with petrol fuel. On operating the engine at higher torque, the fuel consumed using petrol, P85 + E5 + B10, P82.5 + E5 + B12.5, and P80 + E5 + B15 is found as 0.7, 0.65, 0.6, and 0.57 kg/hr, respectively.

Volumetric Efficiency

A variation on the volumetric efficiency of SI engine fuelled with petrol, P85 + E5 + B10, P82.5 + E5 + B12.5, and P80 + E5 + B15 on various engine torque is plotted in Fig. 3. It is noted that there is an increase in volumetric efficiency of the engine with a torque up to 9 N m and reduced after as the temperature of charge is reduced during the induction process. Similarly, the air through the intake manifold increases at higher torque, leading to reduced volumetric efficiency at peak torque. Instant vaporization of blended fuel with iso-butanol resulted in a decreased charge temperature in the intake manifold, which simultaneously increased the volumetric efficiency.

Brake Thermal Efficiency

Figure 4 shows the variations on brake thermal efficiency of the engine fuelled using petrol, P85 + E5 + B10, P82.5 + E5 + B12.5, and P80 + E5 + B15. It is observed that the BTE of the engine increased on increasing the engine torque. Also, it is observed that the BTE of the engine using a higher concentration of iso-butanol is enhanced as the amount of fuel consumed is lowered. Also, the maximum BTE is recorded using 15% iso-butanol and 5% ethanol along with petrol fuel on operating the engine at peak torque. The blend with 15% iso-butanol and 5% ethanol provided highest thermal efficiency of 30% at full load operation of the engine, which can be benchmarked with petrol as 6% increase in brake thermal efficiency.

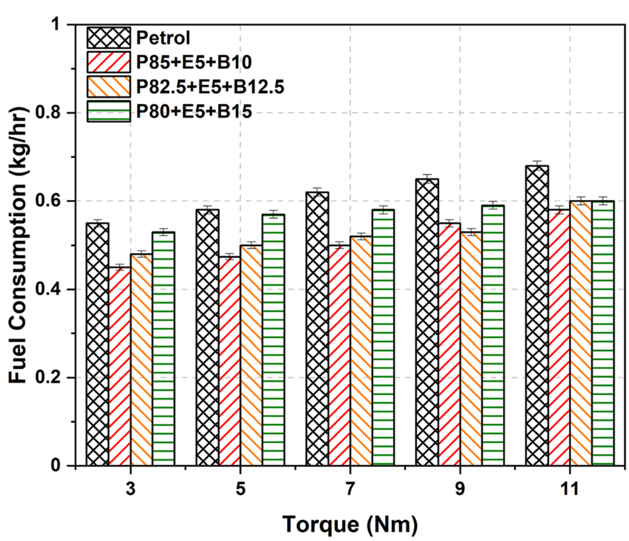

Fig. 2 Fuel consumption variation using prepared petrol blends

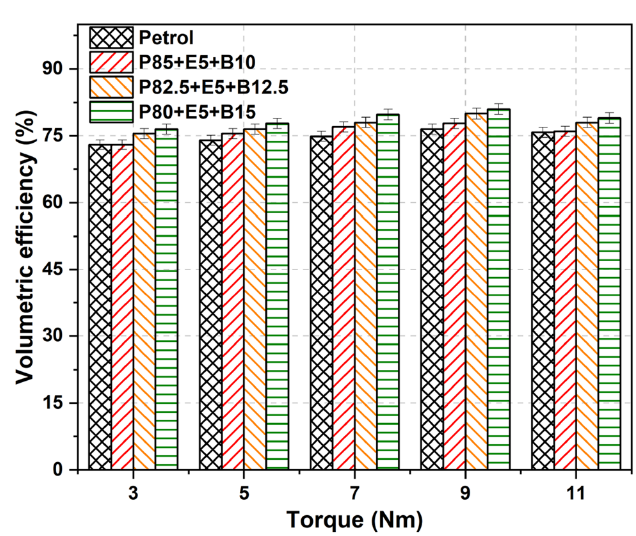

Fig. 3 Volumetric efficiency variation using prepared petrol blends

Specific Fuel Consumption

The variation on specific fuel consumption using a varied concentration of Iso-butanol and a constant ethanol concentration with engine operated at different torque is plotted in Fig. 5. It is clear that on the increased concentration of iso-butanol with the fuel, the SFC reduces as the viscosity of the fuel decreases. While operating the engine at maximum torque, the SFC using a higher concentration (15%) of iso-butanol is almost closer to the petrol blended with 12.5 and 10% iso-butanol with the fuel.

Emission Analysis

Exhaust Emissions

Figures 6,7,8 and 9 show the variation in the different emissions produced after combustion from the engine, such as CO, HC, NOx, and CO2. Effect of iso-butanol and ethanol on petrol fuel on variation in torque over CO emission is plotted in Fig. 6. It can be clearly inferred that on increasing the concentration of iso-butanol with petrol by fixing the constant concentration of ethanol in petrol, the CO emission emitted through the exhaust manifold decreases. As the complete combustion is happening inside the cylinder at a higher concentration of iso-butanol, the CO emissions are reduced. The maximum emission with higher torque from the engine exhibited 2, 1.9, 1.5, and 1.2% by volume using petrol, P85 + E5 + B10, P82.5 + E5 + B12.5, and P80 + E5 + B15, respectively.

The variation in NOx formation using different blends of petrol with iso-butanol and ethanol is plotted in Fig. 7. The petrol fuel exhibited higher NOx emission from the engine which is due to higher in-cylinder pressure developed during the combustion. The maximum emission with higher torque from the engine exhibited 200, 170, 155, and 146 ppm using petrol, P85 + E5 + B10, P82.5 + E5 + B12.5, and P80 + E5 + B15, respectively. Similarly, the variations on HC emission using different compositions of iso-butanol and constant ethanol concentration for different engine torque are plotted in Fig. 8. Lower CO emissions and complete combustion of fuel inside the combustion chamber showed a reduced amount of HC emitted through the exhaust manifold. On higher engine torque, it is observed that the engine HC emission is reduced. It is also inferred from Fig. 8 that the HC emission leading to neat combustion inside the cylinder with the engine operated at a higher toque. With complete combustion of fuel, the formation of CO2 increases, which is

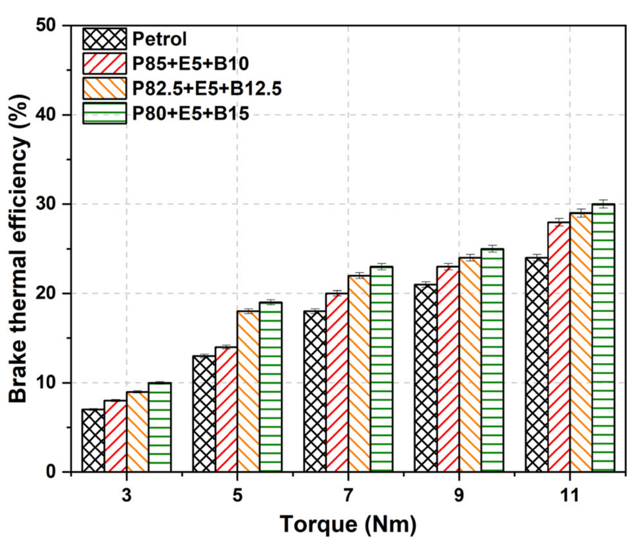

Fig. 4 BTE variation using prepared petrol blends

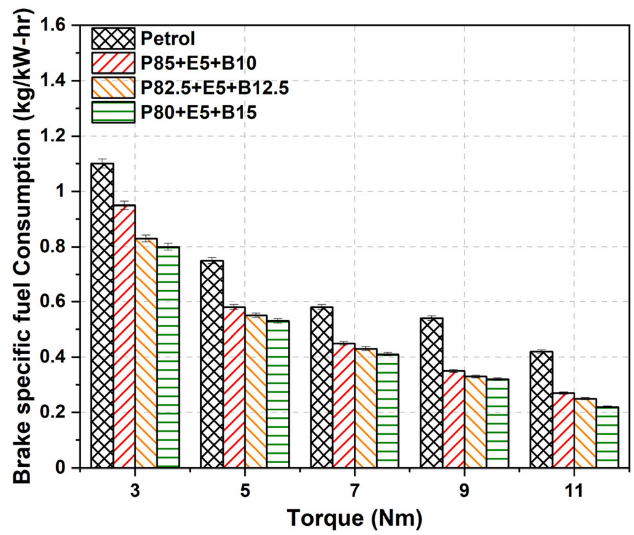

Fig. 5 BSFC variation using prepared petrol blends

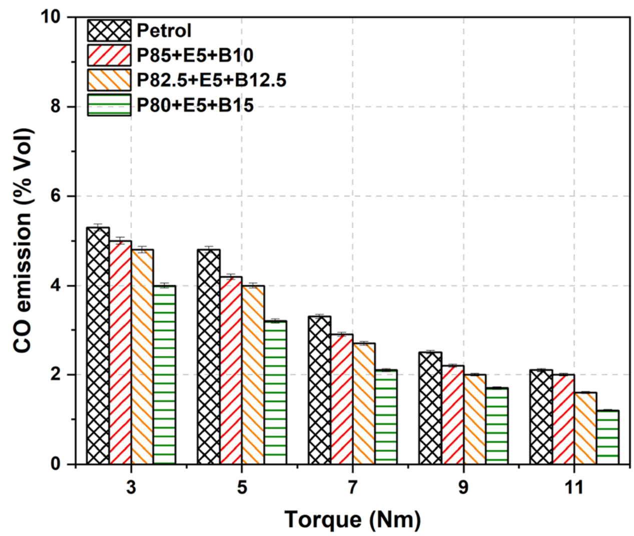

Fig. 6 CO emission variation using prepared petrol blends

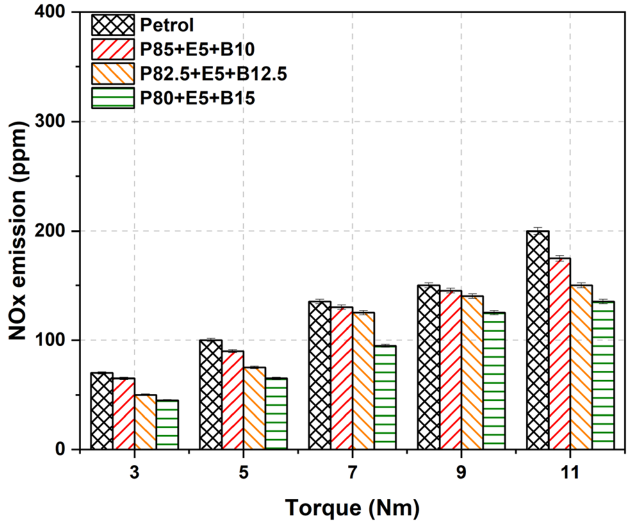

Fig. 7 NOx emission variation using prepared petrol blends

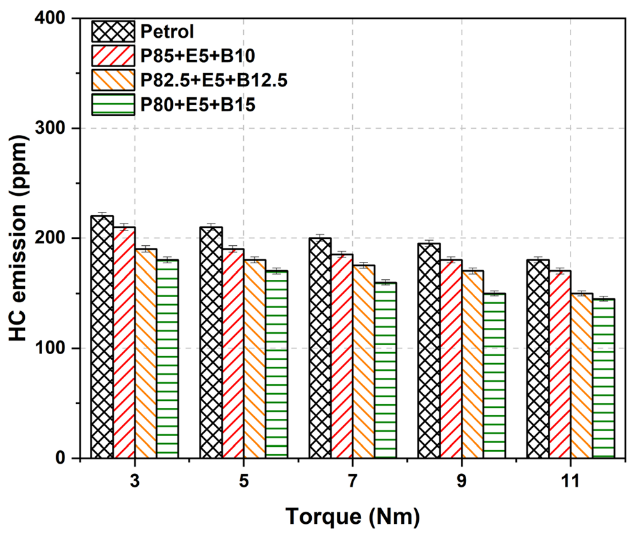

Fig. 8 HC emission variation using prepared petrol blends

plotted in Fig. 9. On increasing the torque of the engine, the CO2 linearly increases, and it is clear that the CO2 emission from the engine is fuelled using P85 + E5 + B10, P82.5 + E5 + B12.5, and P80 + E5 + B15 are higher than that of ordinary petrol. The maximum emission with higher torque from the engine exhibited 6.2, 7, 7.5, and 7.7% by volume using petrol, P85 + E5 + B10, P82.5 + E5 + B12.5, and P80 + E5 + B15, respectively.

Combustion Analysis

Maximum Pressure

The variation in in-cylinder pressure developed using blends of petrol fuel in SI engine is shown in Fig. 10. It is found that the engine fuelled with petrol exhibited higher

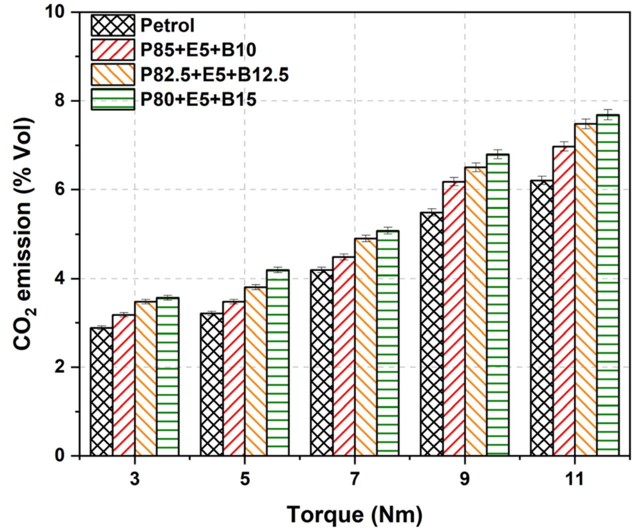

Fig. 9 CO_2 emission variation using prepared petrol blends

in-cylinder pressure while compared to other blended fuel. The peak cylinder pressure developed using petrol is found as 28 bar. On increasing the concentration of iso-butanol with petrol fuel exhibited lower cylinder pressure developed. The peak cylinder pressure using 27.5, 26.3, and 26.1 bar using 10, 12.5, and 15% iso-butanol with petrol fuel, respectively. The decrease in in-cylinder pressure is due to adding iso-butanol and ethanol, which simultaneously decreased the fuel's lower heating value. The significance of higher-octane value and lower heat exhibited by the fuel blend also plays, which enhanced the delay in chain reaction reduced the in-cylinder pressure developed.

Conclusion

- The average reduction in the fuel consumed using blends of 12.5% iso-butanol and 5% ethanol is found as 3.4% while compared to 15% iso-butanol and 5% ethanol with petrol fuel.
- The BTE, and volumetric efficiency improved to about 8.2 and 7.8%, respectively, using 15% iso-butanol and 5% ethanol compared to 12.5% iso-butanol and 5% ethanol. Similarly, the SFC using 12.5% iso-butanol and 5% ethanol reduced by 6.7%.
- The average reduction in CO, HC, and NOx is found as 36.5, 34.3, and 18.2%, respectively, using 15% iso-butanol and 5% ethanol with the engine operated at peak torque condition, whereas the CO_2 emission after the combustion is increased by 19.4% than using petrol fuel.
- The use of 15% iso-butanol and 5% ethanol blended with the petrol fuel improved the engine performance and reduced emission.

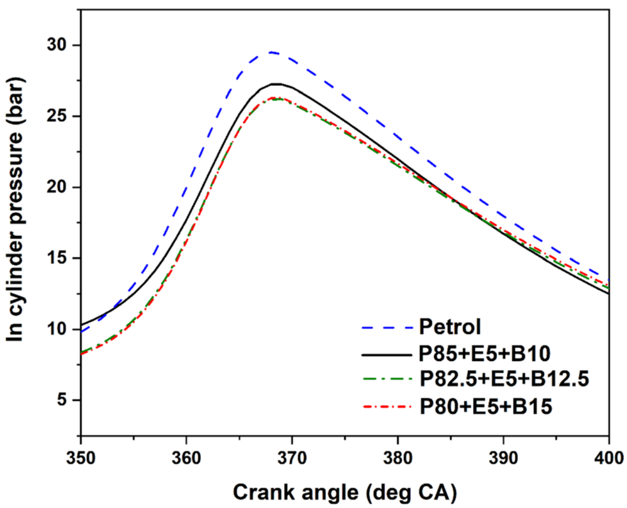

Fig. 10 In-cylinder pressure variation using prepared fuel

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Conflict of Interests The authors declare that there is no competing interest.

References

1. F.N. Alasfour, NOx emission from a spark ignition engine using 30% iso-butanol–gasoline blend: Part 2—ignition timing. Appl. Therm. Eng. **18**(8), 609–618 (1998)
2. D. Balaji, P. Govindarajan, J. Venkatesan, Influence of isobutanol blend in spark ignition engine performance and emissions operated with gasoline and ethanol. Int. J. Eng. Sci. Technol. **2**(7), 2859–2868 (2010)
3. A. Elfasakhany, Experimental investigation on SI engine using gasoline and a hybrid iso-butanol/gasoline fuel. Energy Convers. Manage. **95**, 398–405 (2015)
4. B. Dhanapal, S. Palani, V. Dharmaraj, M.K. Jawahar, An experimental investigation on ethanol blends and 10% ethanol+ isobutanol-gasoline mixtures operated single cylinder four stroke SI bajaj engine. Int. J. Appl. Environ. Sci. **8**(23), 2781–2792 (2013)
5. H. Sharudin, N.R. Abdullah, G. Najafi, R. Mamat, H.H. Masjuki, Investigation of the effects of iso-butanol additives on spark ignition engine fuelled with methanol-gasoline blends. Appl. Therm. Eng. **114**, 593–600 (2017)
6. N. Mittal, R.L. Athony, R. Bansal, C.R. Kumar, Study of performance and emission characteristics of a partially coated LHR SI engine blended with n-butanol and gasoline. Alex. Eng. J. **52**(3), 285–293 (2013)
7. R.V. Bata, V.P. Roan, *Effects of Ethanol and Methanol in Alcohol-Gasoline Blends on Exhaust Emission* (J. Eng., Gas Turbine Power, ASME, 1989), pp. 432–438
8. J.B. Unzelman, US clean air act expand role for oxygenates; oxygenates for the future. Oil Gas J. **89**(15), 44–48 (1991)
9. L.O. Gulder, *Technical Aspect of Ethanol and Ethanol Gasoline Blends as Automotive Fuel* (The scientific and Technical Research Council of Turkey, Project No, 1979), p. 526
10. E.M. Goddger, *Hydrocarbon Fuel* (Macmillan, London, 1975).
11. Houghton-Alico D (1982), Alcohol fuels production and potential, Colorado.
12. M.M. EL-Kassaby, Effect of using differential ethanol-gasoline blends at different compression ratio on SI engine. Alexandria Eng. **32**(3), 135–145 (1993)
13. T.L. Winnington, K.M. Siddiqui, Engine performance on gasohol-the Kenyan experience. Automot Eng. **8**, 12–13 (1983)
14. M.A. Hamdan, B.A. Jubran, The effect of ethanol performance of diesel and petrol engines. Dirasat XII **I**(10), 229–244 (1986)
15. Palmer F H (1986), Vehicle performance of gasoline containing oxygenates, paper C319/86, International conference on petroleum based fuels and automotive applications, London, I. Mech. E. Conference, pp. 36–46.
16. Taljaard H C, Jaardaan CFP, Both JJ (1991), The effect of oxygen content in different oxygenates gasoline blends on performarence and emission in a single cylinder spark ignition engine, SAE 91037.