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Performance Investigation of Spark Ignition Engines (SIE) using Biofuel Blended with N-Propanol Fuel Additive

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Abstract

This experiment studies the suitability of n-propanol in biofuel for the performance improvement of the Spark Ignition Engine (SIE). Literature reported performance limitations of SIE with Ethanol-Gasoline (EG) blends. N-propanol can be an additive due to its good calorific value and non-separating properties. Various blends such as EG, Propanol-Gasoline (PG), and Propanol-Ethanol-Gasoline (PEG) were tested to assert their best potential in an SIE. Experimentation was conducted on a 4-stroke petrol test engine running at 2800 rpm with low fuel blend concentrations and varying Compression Ratio (CR) to investigate its effects on the performance of SIE. Increasing CR improved PEG-fueled engine performance more than gasoline-fueled engines, such as Brake Thermal Efficiency (BTE) and Brake Specific Fuel Consumption (BSFC), and decreased emissions like Carbon Dioxides (CO_2), Carbon Monoxide (CO), and Unburnt Hydrocarbons (HCs). The performance of SIE mainly compared E10 (10% ethanol in gasoline) and E10Pr1.5 (10% ethanol and 1.5% propanol in gasoline) biofuels at different CRs. As compared to E10, E10Pr1.5 reported an increase in BTE from 0.43-0.83%, a significant decrease in BSFC from 0.05-0.37%, a reduction in CO emission from 6.85-9.78%, and a decline in HCs emission from 2.16-3.69%, at different CRs (4.67-7.5) respectively. Results show that a 1.5% addition of propanol in E10 biofuel improves the performance of SIE compared to pure gasoline and EG blend with 10% ethanol in gasoline. E10Pr1.5 shows the highest BTE, lowest BSFC, and lowest emissions of CO and HCs for different CRs. Propanol can be used as a fuel additive in the EG biofuel.

Keywords: *Biofuel, N-Propanol Fuel Additives, Performance Investigation, Spark Ignition Engine (SIE)*

1.0 Introduction

Because of fuel deficits, rising costs, and increased emissions, SIE researchers concentrate more on renewable fuels. One of the most viable options possible today is mixing ethanol with gasoline. Ethanol is superior to gasoline in some properties, such as the anti-knock function at a higher CR, which enhances the efficiency of the SIE. The government of India adopted a 10 % ethanol blending policy with gasoline as E10 reported efficiency enhancement in SIE compared to gasoline as notified in 2019 by the Ministry of Road Transport & Highways[1]. Using binary fuel E15, the BTE, CO, and NOx decrease, and BSFC and HCs increase the current SIE compared

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to E0 and E-10[2]. The octane number and Reid Vapor Pressure (RVP) rise while caloric value reduces to 10% ethanol, and RVP falls with a further increase of its % in gasoline[3]. There is also a need for a fuel additive that could be added to the E-10 blend to boost engine BTE. Propanol exhibits promising characteristics such as high calorific and a more significant octane number than ethanol and other alcohols[4].

Numerous researchers investigated the performance features of SIE with different EG mixes. When spray evaporation and combustion properties of single gasoline and EG mix (E85) were compared, EG blends demonstrated more stable combustion because ethanol has a greater evaporation rate than gasoline[5]. Studying the dual fuel of alcohol-gasoline in SIE might successfully expand the knocking limit in a stoichiometric state, boosting fuel efficiency[6]. Adding ethanol to the EG mix improves BTE due to more oxygen %, which boosts engine torque while decreasing CO and UHC emissions[7-9]. The fuel economy of stable homogenous MEG blends was examined, and comparable findings were observed with the MEG mix[10,11]. MEG is recommended for mild CO, HCs, and high volumetric efficiency, torque, and power in SIE[12-14]. Using 20%, EG blends reduced CO and HC emissions by 20% in wall-guided direct injection vehicles[15].

The researchers also mentioned the drawback of greater ethanol concentrations. The E22 mix produced more CO2 and NOX[16]. Ethanol% should be between 20-30% for a better cold start of SIE[17]. Biofuel and biodiesels can be derived from vegetables and fruits; the author has already worked on the performance evaluation of diesel using Cottonseed Oil and Eucalyptus Oil and found that its use in a diesel engine can give optimum performance. The problem of fuel import can be addressed[18,19]. Similarly, some researchers tried ethanol generated from grape pomace by 10% to 30% mixed with gasoline[20]. Carbonyls like formaldehyde and acetaldehyde increased linearly in EG blends, according to emissions from two-wheelers operated on gasoline with varied EG mixes ranging from 10% to 50%[21].

The impact of CR was also investigated; at a typical air-fuel ratio, BTE rose with CR, while BSFC dropped[22]. In a small engine, ethanol fuel with a high CR (10/1) boosts power as the CR grows and the BSFC lowers, but NOx emissions increase[23]. The significance of designing a modified SIE that can operate on mid-level ethanol blends was emphasized to study the combustion with EG blends[24,25]. Soot production and emission in the engine are affected by blend quality, engine design, and operation circumstances[26]. In SIE, gasoline with EG mixes increases the engine's CR without banging. The knock is reduced if the injection time is held with the intake valves open. The CR impact on the Ricardo Variable Compression Ratio (VCR) SI engine's Break Power (BP), BTE, MEP (Mean Effective Pressure), and BSFC was also investigated. At a CR of 9 (max), the highest BP, BTE, MEP, and reduced BSFC were reached[27-29]. Further investigation on knocks resistance elements in ethanol-hydrocarbon blends shows that the ethanol's direct injection with gasoline port improves efficiency in SIE since the enhanced latent heat of vaporization and charge cooling influence CR[30,31].

A quick compression machine evaluated ethanol's auto ignition and heat release properties with contents ranging from 0 to 30[32]. Employing ethanol as a mixing fuel to a negligible level in alcohol improves some of SIE's combustion and emission aspects. A more significant proportion of ethanol in alcohol causes additional difficulties, such as increased CO_2, NOx, cold start, soot formation, etc. A smaller amount of ethanol in a blend performed admirably and is suitable as a market substitute for gasoline. To alleviate ethanol shortages, higher alcohols have been suggested[33]. Adding 1.5% butanol to the EG mixture gives the optimum performance of SIE[34].

Experimenting with the combustion parameters of more excellent alcohol/gasoline blends revealed that higher alcohol-to-gasoline ratios resulted in quicker flames. A scientific paper on using sustainable oxygenates as blending components in gasoline. Higher alcohols have been discovered to have considerable benefits over ethanol, including their high energy density, reduced gasoline/mixture vapor pressure, decreased water resistance, and excellent material compliance[35,36]. Another research found that when the carbon concentration rises, so does the alcohol melting point. RON and MON decrease as the carbon concentration increases. The knock resistance of iso-structures is more excellent than that of the n-structure[37]. Iso-propanol was also investigated as a fuel in SIE with homogenous charge compression[38]. Propanol may be created spontaneously in tiny amounts during numerous fermentation processes. Propanol is produced industrially using catalytic propionate aldehyde hydrogenation. The octane number of 1-propanol (n-propanol) is high. It may be used as a fuel additive in SIE[39].

Higher alcohols have been discovered to have considerable benefits over ethanol, including higher energy density, lower gasoline/mixture vapor pressure, reduced water resistance, and enhanced material compliance. The alcohol melting point rises as the carbon count rises, while RON and MON fall as the carbon count increases. N-structures have a slightly higher boiling point and lower knock resistance than iso-structures. Propanol may be created naturally in tiny amounts through various fermentation and industrial processes. Since 1-Propanol (n-propanol) has a high-octane value, it may be used as a fuel additive in SIE.

2.0 Experimentation

2.1 Fuel Selection and Measurement of Fuel Properties

We choose n-propanol as a fuel additive from the alcohol group and fuel base as gasoline (RON-96). Properties like density, calorific value, RON, and oxygen percentage are vital in evaluating fuel. Chemicals (n-propanol and ethanol) supplied by SAM Equipment and Scientific Suppliers in Nagpur were blended, and their fuel properties were tested at Anacon Laboratory Nagpur before trials on the testing engine. The Indian standard test methods test fuel properties for petroleum and its products (IS 1448 P: 16, IS 1448 P: 21, IS 1448 P: 7). The absorption spectra method is used to find Fuel's RON, FTIR. The Oxygen percentage is determined mathematically

2.2 Properties of Optimum Blends

Experimentation was started with E0, E5, E10, and E15 to decide targeted properties for blends. E10 reported the highest BTE and lowest BSFC. Also, BTE increased from E5 to E10 but decreased for E15. The experimentation was continued with Pr5 and Pr10 blends to identify the suitability of binary blends of propanol with gasoline. Still, E10 reported higher BTE as compared to Pr5 and Pr10. BTE decreases from Pr5 to Pr10 since propanol has more viscosity than ethanol and gasoline. We prepare n-propanol, ethanol, and gasoline blends to maintain ternary blend calorific values and octane numbers to achieve higher BTE than E10. Also, the octane number of blends is maintained more than E10. This is achieved by adding the proper % of propanol in E10. While making blends, viscosity is held in the permissible range. The targeted properties of blends are given in Table 1

Table 1. Targeted properties of blends

Properties /Parameters	Measured Values
Calorific Value	≥ 42036 kJ/kg
RON	≥ 97.0
Viscosity	0.7783- 0.94 cSt
Weight of Oxygen content	3.4 - 5.2 %
The volume of Petroleum displacement	> 10%

2.3 Blend Preparation

Binary blends (E5, E10, E15, Pr5, Pr10) are prepared volumetrically. For the optimum ternary blends as per targeted properties, different ternary blends (E10Pr1.5, E10Pr2.5, E10Pr3.5) of various alcohols with gasoline are prepared. Table 2 shows the composition of binary, ternary, and mixed blends of ethanol and n-propanol with gasoline. Also, Tables 3 and 4 show their physicochemical properties.

2.4 Experimental Setup

The experimental system uses a 2.5 kW, single cylinder with 256 Cubic Centimeter (cc) volume, 70mm bore diameter, and 66.7 mm stroke length. An electronic ignition system can change CR from 2.5 to 9. Computerized test rig with an air-cooled four-stroke petrol engine, an eddy current dynamometer, a torque control panel, a five-gas analyzer to record emissions, and a computer to record all input-output parameters. Head-piston assemblies improve CR transition above the main head. Set CR with hand wheel-screw rod assembly. The lowest auxiliary piston position optimizes CR air-cooled flywheel engines with water-cooled variable compression ratio heads. Load cells measure fuel utilization. K-type thermocouples (0-600 ^{0}C)

Table 2. Volumetric composition of blends

Blends	Gasoline	Ethanol	Propanol
E5	95.0 %	05.0 %	0.00 %
E10	90.0 %	10.0 %	0.00 %
E15	85.0 %	15.0 %	0.00 %
Pr5	95.0 %	0.00 %	05.0 %
Pr10	90.0 %	0.00 %	10.0 %
E10Pr1.5	88.5 %	10.0 %	01.5 %
E10Pr2.5	87.5 %	10.0 %	02.5 %
E10Pr3.5	86.5 %	10.0 %	03.5 %

Table 3. Chemical and Physical Properties Fuels and their Blends

SN	Parameters	Unit	Test Method	Gasoline	Ethanol	E5	E10	E15
1	Viscosity	cSt	IP 71	0.6	1.52	0.646	0.692	0.738
2	Flash point	^{O}C	IS 1448 P:21	-43	16	<-35	<-35	<-35
3	RON	-	By FTIR	96	107	96.55	97.1	97.65
4	Calorific value	kJ/kg	IS 1448 P:7	43500	28865	42768	42037	41305
5	Density at 250C	g/cm^3	IS 1448 P:16	0.7375	0.794	0.740	0.743	0.746
6	Sp. heat capacity	J/kg. K	IP-2010	2227	2437	2237	2248	2258
7	Oxygen % by weight	%	-	0	34.73	1.735	3.47	5.205

measure temperatures. Engine head piezo electronics pressure sensors detect combustion chamber pressure at different loads. A water-cooling adopter holds the sensor. Low-noise wires connect the sensor and signal conditioner. Figure 1 shows a schematic of the setup. Before testing, volumetric blends of E5, E10, E15, Pr5, Pr10, E10Pr1.5, E10Pr2.5, & E10Pr3.5 were created as shown in Table 2.

The first engine was driven with gasoline for CR 4.67 for 15-20 minutes at 2800 rpm to attain thermal equilibrium. A variac on the control panel varied the load from zero to full. Each reading was stabilized for 15-20 minutes. Software and sensors recorded input load, fuel and air mass flow rates, combustion chamber pressure, air-fuel mixture intake temperature, exhaust gas temperature, and engine speed. The researchers tested several mixtures after gasoline. Following each blend trial, the engine ran until it

Table 4. Chemical and physical properties of N-propanol and its blends

SN	Test Parameter	Unit	Test Method	Blends Test Result					
				N-Pr.	**Pr5**	**Pr10**	**E10Pr1.5**	**E10Pr2.5**	**E10Pr3.5**
1	Viscosity	cSt	IP 71	2.3	0.685	0.77	0.718	0.735	0.752
2	Flash point	°C	IS1448 P:21	22	<-35	<-35	<-35	<-35	<-35
3	RON	-	By FTIR	118	97.1	98.2	97.43	97.65	97.87
4	Calorific value	kJ/kg	IS 1448 P:7	30680	42859	42218	41844	41716	41588
5	Density at 25 °C	g/cm^3	IS 144P:16	0.896	0.745	0.753	0.746	0.747	0.749
6	Sp. heat capacity	J/kg.K	IP-2010	2390	2235	2243	2250	2252	2253
7	Oxygen % by wt.	%	-	26.62	1.331	2.662	3.8693	4.1355	4.4017

Legends Details:
1. Fuel tank
2. The control unit
3. Adjustable compression ratio wheel
4. Engine
5. Eddy current Dynamometer
6. The water flow control unit
7. Calorimeter
8. Exhaust pipe
9. Connection to a control unit
10. Computer
11. Base
12. Five gas Analyzer

Figure 1. Experimental setup.

entirely devoured the sample to ensure the prior sample did not affect the subsequent blends. CR 5.5, 6.5, and 7.5 were processed similarly. Five gas analyzers recorded exhaust pollutants.

2.5 Experimental Procedure

The experiments are performed on a single-cylinder air-cooled SIE linked with an eddy current dynamometer. Pure petrol experiments were conducted at various compression ratios 4.67, 5.5, 6.5, and 7.5. The compression ratio was set at 4.67; we started the engine using a rope and pulley and let it warm up for 10-15 minutes. The engine was permitted to run at 2800 rpm with a load ranging from o to max load condition. Each reading was given 10 minutes to stabilize. Exhaust gas analyzer, Sensors, and software were used to measure various performance and emission parameters—A 15-minute cooling time was used between each reading. Before adding new mixes to the gasoline tank, it was entirely drained and ran till it consumed fuel in the carburetor and all the lines. The tank was now filled with a fresh mix. The same method was followed for various mixes with varying compression ratios.

3.0 Results and Discussions

3.1 Effect of CR and Blending % on BTE and BSFC

Figure 2 depicts the effect of CR on the BTE of different fuels and their mixes. Except for E0, i.e., pure gasoline, where BTE first rises and begins to decrease at CR5, BTE of other fuel blends increases with an increase in CR. Since n-propanol has a higher RON than gasoline and ethanol, the BTE of EPr1.5 is more significant than E0 and E10 at all CR. BTE drops when the amount of n-propanol in PG binary blends and PEG ternary combinations increases owing to its lower calorific value than gasoline.

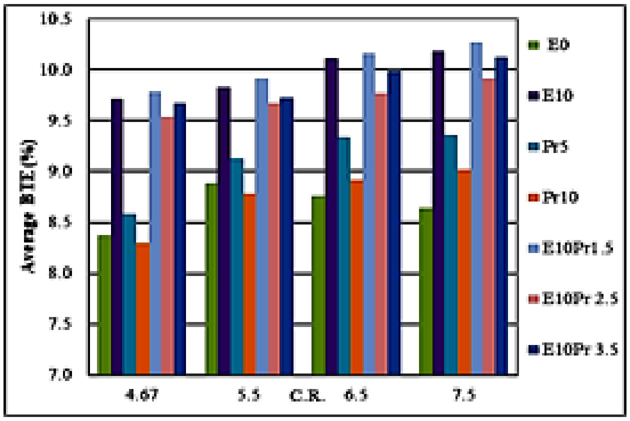

Figure 2. Comparison of average BTE % at various CRs for different blends.

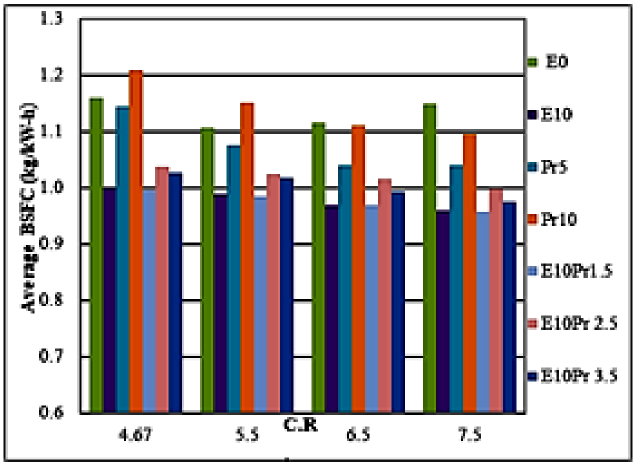

Figure 3. Comparison of average BSFC at various CRs for different blends.

As compared to gasoline, n-propanol contains a more significant amount of oxygen (26.62%) than does gasoline (0%), which aids in optimal combustion and boosts the thermal efficiency of all n-propanol blends (Pr5, E10Pr1.5, E10Pr2.5, and E10Pr3.5). The BTE of PG and PEG is less than E10 owing to their lower calorific value; however, the BTE of the E10Pr1.5 mix is more than E10. This might be because E10Pr1.5 has a more significant oxygen % than E10, which aids combustion. The % increase in BTE from E10Pr1.5 to E0 and E10 is 11.55% to 18.86% and 0.43% to 0.83% for CR 4.67 to 7.5, respectively.

Figure 3 shows the average BSFC achieved with various fuels and their mixes for CR 4.67 to 7.5. BSFC declines except E0, which is pure gasoline, for all blends at increasing CR. Since propanol has a lower calorific value than gasoline, BSFC rises with increased n-propanol in PG and PEG mixes. This is due to the inverse connection that exists between BTE and BSFC. E10Pr1.5 had the lowest BSFC at each CR of all mixes tested. For CR 4.67 to 7.5, the % reduction in BSFC for E10Pr1.5 to E0 and E10 is 11.04% to 16.73% and 0.05% to 0.73%, respectively.

An increase in % of n-propanol in PG and PEG shows improvement in BSFC due to its lower calorific value. Among all combinations, EPr1.5 reported the lowest BSFC at different CRs. The % decrement in BSFC for EPr1.5 to E0 and E10 is 11.04% to 16.73% and 0.05% to 0.73 %, for CR 4.67 to 7.5, respectively.

3.2 Effect of CR and % of Blending on CO, HCs, and NOx Emissions

3.2.1 CO Emission

Figure 4 shows the average CO values achieved with various fuels and mixes against differing CRs, ranging from 6.67 to 7.5. It steadily declines as the proportion of ethanol in mixes increases (E5, E10 & E15). Adding n-propanol to EG blends (E10Pr1.5, E10Pr2.5, and E10Pr3.5) decreases CO emissions at every CR compared to E0 and E10 since it has more oxygen than gasoline. Gasoline has no oxygen, whereas E15 has the most significant proportion of oxygen among all mixes. As a result, it reports the most negligible CO emission with variable CR. For all blends, CO emission falls as CR increases. The % decrements of CO emission of E10Pr1.5 to E0 and E10 are 24% to 36% and 6% to 10 % for CR 4.67 to 7.5, respectively[19].

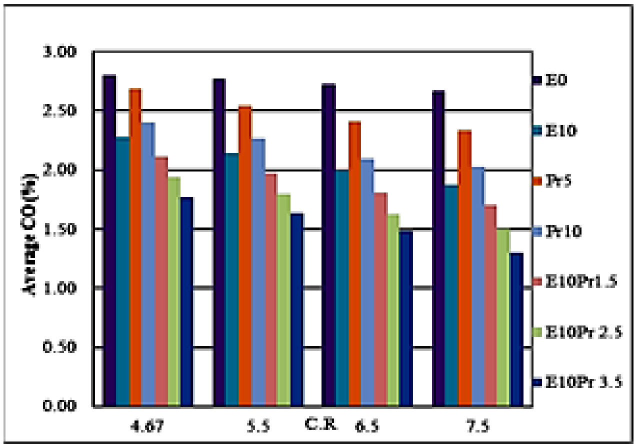

Figure 4. Comparison of average CO emission at various compression ratios.

3.2.2 HCs Emission

Figure 5 details the average hydrocarbon values obtained with different blends for varying CR. The average values of hydrocarbon continuously reduce with an increase in the % of propanol.

Propanol addition results in the oxygen enrichment of the blend. A higher % of oxygen in propanol improves combustion, which reduces HC emissions. Average HC emission decreases with increased CR and E15, showing fewer HC emissions. The % decrements of HC emission for fuel E10Pr1.5 to E0 & E10 are 13 to 21 % and 2 to 4 %, for CR 4.67-7.5, respectively.

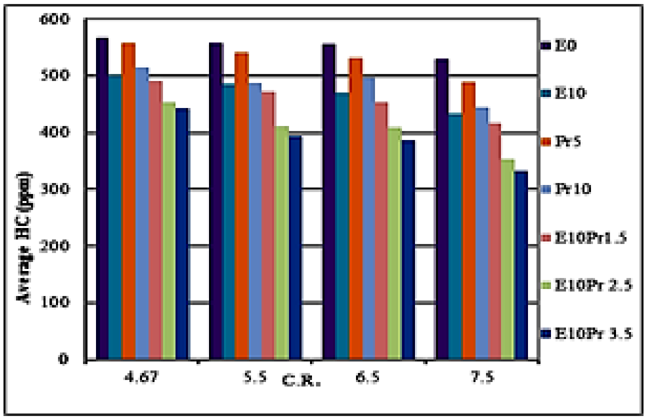

Figure 5. Comparison of average HC emission at various compression ratios.

3.2.3 NOx Emission

Figure 6 compares average NOx emissions from different blends for various CRs. Higher CR leads to an increase in combustion temperature, generating more NOx. As a result, it increases. In propanol-mixed fuels, E10Pr3.5 produced more NOx at each CR than E0 and E10, but E10Pr1.5 produced less NOx than E10Pr3.5. The highest NOx emission for E10Pr1.5 (90 ppm) is recorded at CR 7.5. At this CR, the most significant % increase in NOx emission for the E10Pr3.5 and E10Pr1.5 compared to E0 is 46.10% and 4.41%, respectively.

NOx emissions can be reduced by providing water jackets around engines, which lowers the engine temperature. Many methods, including the standard rail system, exhaust gas recirculation (EGR), Miller cycle, direct water injection, emulsified fuel, and selective catalytic reduction (SCR), are available for NOx reduction[40-42].

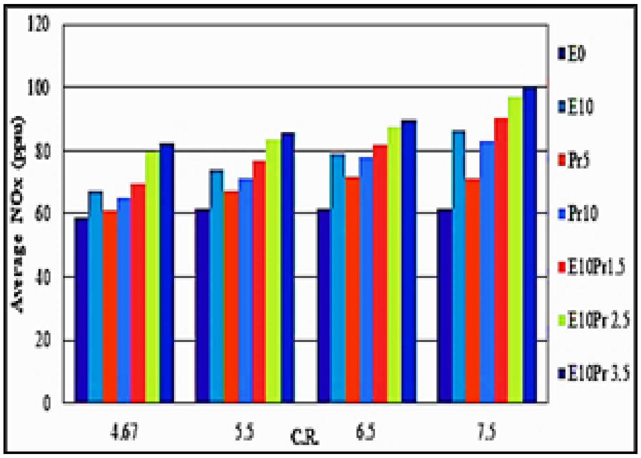

Figure 6. Variation of NOx emission with compression ratio for different fuels and their blends.

4.0 Conclusions

In this work, different blended fuels like ethanol-gasoline (EG), propanol-gasoline (PG), and propanol-ethanol-gasoline (PEG) were used to test the performance of the engines with varying compression. Blends prepared in the laboratory were used for experimentation in SIE to see its (blends) comparative performance on the engine's performance. PEG fuel blends slightly improved the BTE, and lower BSFC, CO, and HCs engine emissions than gasoline (Pure). However, they show lower BTE, BSFC, and higher emissions than PG. The thermal performance of SIE increases with higher CR, which needs higher octane number fuel to avoid the knocking effect. Compared to E10, E15 has a higher octane number, but E15 records a lower BTE than E10. So, there are better options than E15 at a higher CR, i.e., N-propanol in the EG blends with its lower concentration as an additive. Compared to E0, the binary blends E10 has maximum BTE from 10.65% to 17.88%, low BSFC from 10.71% to 16.58%, low CO and HC emission from 18.8% to 32.2% and 11.59% to 18.33% respectively for CRs between 4.67 to 7.5 respectively. E10Pr1.5 reported a maximum % increment in BTE compared to E10 (0.43% to 0.83 %.) for different CRs (4.67 to 7.5). Also, E10Pr1.5 reported a maximum % decrement in BSFC compared to E10 (0.05-0.37 %.) for different CRs (4.67 – 7.5). The % decrement in CO emission for E10Pr 1.5, compared to E10 for different CR (4.67 – 7.5), is 6.85% to 9.78 %. The % decrement in HC emission for E10Pr 1.5 blends compared to E10 for different CR (4.67 – 7.5) ranges from 2.16% to 3.69%. Results show that a 1.5 % addition of propanol in E10 fuel improves BTE compared to E0 and E10: E10Pr1.5 and lowers BSFC, CO, and HC emissions for different CRs.

5.0 Acknowledgement

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6.0 References

1. Sakthivel P, Subramanian KA, Mathai R. Indian scenario of ethanol fuel and its utilization in the automotive transportation sector. Resour Conserv Recycl. 2018; 132:102-20. https://doi.org/10.1016/j.resconrec.2018.01.012
2. Yoon SK. Application characteristics of bioethanol as an oxygenated fuel additive in diesel engines. Appl Sci. 2023; 13. https://doi.org/10.3390/app13031813
3. Kheiralla AF, El-Awad M, Hassan MY, Hussen MA, Osman HI. Effect of ethanol–gasoline blends on fuel properties characteristics of spark ignition engines. Univ KHARTOUM Eng J. 2011; 1(2):22-8.
4. Gong J, Cai J, Tang C. A comparative study of emission characteristics of propanol isomers/gasoline blends combined with EGR. SAE Int J Fuels Lubr. 2014; 7(1):200-6. https://doi.org/10.4271/2014-01-1454
5. Iodice P, Senatore A, Langella G, Amoresano A. Advantages of ethanol-gasoline blends as fuel substitute for last generation Si engines. Environ Prog Sustain Energy. 2017; 36(4):1173-9. https://doi.org/10.1002/ep.12545
6. Liu H, Wang Z, Long Y, Wang J. Dual-Fuel Spark Ignition (DFSI) combustion fuelled with different alcohols and gasoline for fuel efficiency. Fuel. 2015; 157:255-60. https://doi.org/10.1016/j.fuel.2015.04.042
7. Hsieh W-D, Chen R-H, Wu T-L, Lin T-H. Engine performance and pollutant emission of an SI engine using ethanol-gasoline blended fuels. Atmos Environ. 2002; 36(3):403-10. https://doi.org/10.1016/S1352-2310(01)00508-8
8. Al-Hasan M. Effect of ethanol-unleaded gasoline blends on engine performance and exhaust emission. Energy Convers Manag. 2003; 44(9):1547-61. https://doi.org/10.1016/S0196-8904(02)00166-8
9. Yüksel F, Yüksel B. The use of ethanol-gasoline blend as a fuel in an SI engine. Renew Energy. 2004; 29(7):1181-91. https://doi.org/10.1016/j.renene.2003.11.012
10. Eyidogan M, Ozsezen AN, Canakci M, Turkcan A. Impact of alcohol-gasoline fuel blends on the performance and combustion characteristics of an SI engine. Fuel. 2010; 89(10):2713-20. https://doi.org/10.1016/j.fuel.2010.01.032
11. Waluyo B, Setiyo M, Saifudin, Wardana ING. Fuel performance for stable homogeneous gasoline-methanol-ethanol blends. Fuel. 2021; 294. https://doi.org/10.1016/j.fuel.2021.120565
12. Pikūnas A, Pukalskas S, Grabys J. Influence of composition of gasoline - ethanol blends on parameters of internal combustion engines. J KONES Intern Combust Engines. 2003; 10.
13. Chen R, Nishida K. Spray evaporation of ethanol-gasoline-like blend and combustion of ethanol-gasoline blend injected by hole-type nozzle for direct-injection spark ignition engines. Fuel. 2014; 134:263-73. https://doi.org/10.1016/j.fuel.2014.05.082
14. Elfasakhany A. Investigations on the effects of ethanol-methanol-gasoline blends in a spark-ignition engine: Performance and emissions analysis. Eng Sci Technol an Int J. 2015; 18(4):713-9. https://doi.org/10.1016/j.jestch.2015.05.003

15. Iodice P, Senatore A, Langella G, Amoresano A. Effect of ethanol-gasoline blends on CO and HC emissions in last generation SI engines within the cold-start transient: An experimental investigation. Appl Energy. 2016;179:182-90. https://doi.org/10.1016/j.apenergy.2016.06.144
16. Costa RC, Sodré JR. Hydrous ethanol vs. gasoline-ethanol blend: Engine performance and emissions. Fuel. 2010; 89(2):287-93. https://doi.org/10.1016/j.fuel.2009.06.017
17. Chen R-H, Chiang L-B, Chen C-N, Lin T-H. Cold-start emissions of an SI engine using ethanol-gasoline blended fuel. Appl Therm Eng. 2011; 31(8):1463-7. https://doi.org/10.1016/j.applthermaleng.2011.01.021
18. Suryawanshi PN, Ladekar CL. Experimental Investigation of single cylinder diesel engine operated on eucalyptus oil and cotton seed oil as biodiesel. Int Eng Res J. 2017; Special Ed(PGCON-MECH-2017):1-6.
19. Suryawanshi PN, Suyog R. Patil PCLL. Experimental investigation of performance , combustion and emission in diesel engine by using biodiesel blends of cottonseed oil and eucalyptus oil. Int Eng Res J. 2016; (3):165-70.
20. Iodice P, Langella G, Amoresano A. Ethanol in gasoline fuel blends: Effect on fuel consumption and engine out emissions of SI engines in cold operating conditions. Appl Therm Eng. 2018; 130:1081-9. https://doi.org/10.1016/j.applthermaleng.2017.11.090
21. Sakthivel P, Subramanian KA, Mathai R. Experimental study on unregulated emission characteristics of a two-wheeler with ethanol-gasoline blends (E0 to E50). Fuel. 2020; 262. https://doi.org/10.1016/j.fuel.2019.116504
22. Yücesu HS, Topgül T, Çinar C, Okur M. Effect of ethanol-gasoline blends on engine performance and exhaust emissions in different compression ratios. Appl Therm Eng. 2006; 26(17):2272-8. https://doi.org/10.1016/j.applthermaleng.2006.03.006
23. Celik MB. Experimental determination of suitable ethanol-gasoline blend rate at high compression ratio for gasoline engine. Appl Therm Eng. 2008; 28(5):396-404. https://doi.org/10.1016/j.applthermaleng.2007.10.028
24. Sakthivel P, Subramanian KA, Mathai R. Comparative studies on combustion, performance and emission characteristics of a two-wheeler with gasoline and 30% ethanol-gasoline blend using chassis dynamometer. Appl Therm Eng. 2019; 146:726-37. https://doi.org/10.1016/j.applthermaleng.2018.10.035
25. Zhu P, Tao ZX, Li C, Liu QY, Shao Q, Yang R, et al. Experimental study on the burning rates of Ethanol-Gasoline blends pool fires under low ambient pressure. Fuel. 2019; 252:304-15. https://doi.org/10.1016/j.fuel.2019.04.118
26. Catapano F, Di Iorio S, Luise L, Sementa P, Vaglieco BM. Influence of ethanol blended and dual fueled with gasoline on soot formation and particulate matter emissions in a small displacement spark ignition engine. Fuel. 2019; 245:253-62. https://doi.org/10.1016/j.fuel.2019.01.173
27. Koç M, Sekmen Y, Topgül T, Yücesu HS. The effects of ethanol-unleaded gasoline blends on engine performance and exhaust emissions in a spark-ignition engine. Renew Energy. 2009; 34(10):2101-6. https://doi.org/10.1016/j.renene.2009.01.018
28. Kim N, Cho S, Min K. A study on the combustion and emission characteristics of an SI engine under full load conditions with ethanol port injection and gasoline direct injection. Fuel. 2015; 158:725-32. https://doi.org/10.1016/j.fuel.2015.06.025
29. Aina T, Folayan CO, Pam G. Influence of compression ratio on the performance characteristics of a spark ignition engine. Adv Appl Sci Res. 2012; 3:1915-22.
30. Chupka GM, Christensen E, Fouts L, Alleman TL, Ratcliff MA, McCormick RL. Heat of vaporization measurements for ethanol blends up to 50 volume percent in several hydrocarbon blendstocks and implications for knock in SI engines. SAE Int J Fuels Lubr. 2015; 8(2):251-63. https://doi.org/10.4271/2015-01-0763
31. Huang Y, Hong G, Cheng RHX. Investigation to charge cooling effect of evaporation of ethanol fuel directly injected in a gasoline port injection engine. SAE/KSAE 2013 International Powertrains, Fuels & Lubricants Meeting; 2013. p. 13. https://doi.org/10.4271/2013-01-2610
32. Cheng S, Saggese C, Kang D, Goldsborough SS, Wagnon SW, Kukkadapu G, et al. Autoignition and preliminary heat release of gasoline surrogates and their blends with ethanol at engine-relevant conditions: Experiments and comprehensive kinetic modeling. Combust Flame. 2021; 228:57-77. https://doi.org/10.1016/j.combustflame.2021.01.033
33. Gautam M, Martin DW. Combustion characteristics of higher-alcohol/gasoline blends. Proc Inst Mech Eng Part A J Power Energy. 2000; 214(5):497-511. https://doi.org/10.1243/0957650001538047

34. Kothare C, Ladekar C, Kongre S. Experimental investigation of N-Butanol as a fuel additive for Spark Ignition (S.I.) engine. Mater Today Proc. 2022. https://doi.org/10.1016/j.matpr.2022.12.064
35. Yanowitz J, Christensen E, McCormick R. Utilization of renewable oxygenates as gasoline blending components. Contract. 2011; 303(47):275-300. https://doi.org/10.2172/1024518
36. Kothare CB, Kongre S, Bhope D V. Effect of Higher Alcohols addition on the performance characteristics of variable compression four stroke Spark Ignition engine. Int J Eng Technol. 2016; 3(2).
37. Wallner T, Ickes A, Lawyer K. Analytical assessment of C2-C8 alcohols as spark-ignition engine fuels BT - Proceedings of the FISITA 2012 World Automotive Congress. In Berlin, Heidelberg: Springer Berlin Heidelberg; 2013. p. 15-26. https://doi.org/10.1007/978-3-642-33777-2_2
38. Ipci D, Yılmaz E, Aksoy F, Uyumaz A, Polat S, Solmaz H. The effects of iso-propanol and n-heptane fuel blends on HCCI combustion characteristics and engine performance. 2015; 12:2015-64.
39. Kothare CB, Kongre S, Bhope D V. Experimental investigation of effect of Gasoline-higher alcohol blend on performance characteristic of four stroke Spark Ignition engine at variable compression ratio. 2016 International conference on electrical, electronics, and optimization techniques (ICEEOT). IEEE; 2016. p. 27-33. https://doi.org/10.1109/ICEEOT.2016.7755182
40. Okumuş F, Kökkülünk G. Nitrogen Oxides (NOx) reduction methods used in marine diesel engine. J Mar Eng Technol. 2023; 3(1):34-44. https://doi.org/10.58771/joinmet.1294204
41. Deng J, Wang X, Wei Z, Wang L, Wang C, Chen Z. A review of NOx and SOx emission reduction technologies for marine diesel engines and the potential evaluation of liquefied natural gas fuelled vessels. Sci Total Environ. 2021; 766. https://doi.org/10.1016/j.scitotenv.2020.144319 PMid:33421776
42. Praveena V, Martin MLJ. A review on various after treatment techniques to reduce NOx emissions in a CI engine. J Energy Inst. 2018; 91(5):704-20. https://doi.org/10.1016/j.joei.2017.05.010

Nomenclature			
BSFC	Specific Fuel Consumption (Brake)	E10P3.5	3.5% n-pentanol mixed with E10 blend
BTE	Thermal efficiency (Brake)	EG	Ethanol-Gasoline
CRs	Compression Ratios	HCs.	Unburnt Hydrocarbons
CO	Carbon-monoxide	MEG	Methanol-Ethanol-Gasoline
CO_2	Carbon-dioxide	MEP	Mean Effective Pressure
E0	Pure Gasoline	MON	Motor octane number
E5	05% ethanol mixed with gasoline	NOx	Nitrogen oxides
E10	10% ethanol mixed with gasoline	Pr5	5% n-pentanol mixed with gasoline
E15	15% ethanol mixed with gasoline	Pr10	10% n-pentanol mixed with gasoline
E22	22% ethanol mixed with gasoline	PG	Propanol Gasoline
E85	85 % ethanol mixed with gasoline	PEG	Propanol-Ethanol-Gasoline
E10P1.5	1.5% n-pentanol mixed with E10 blend	RON	Research octane number
E10P2.5	2.5% n-pentanol mixed with E10 blend	SIE	Spark Ignition Engine