Optimization of Compression Ratio & Fuel Blend for SI Engine Using N-Butanol and Petrol Blends

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Abstract: **The consumption of crude oil has seen an increase of more than 40% worldwide in past few decades. In India, about 72% of crude oil is imported for fulfilment of requirements in coming years. The sources for crude oil are also limited and are bound to get depleted very soon. Apart from the shortage of fuel resources, emissions resulting from burning of fossil fuels in the engine is also a big problem. The gases emitted from the engine are very hazardous to human beings as well as animals. In the current global scenario,, it is necessary to find new fuels which are renewable and can be developed easily. A new alcohol-based fuel n-butanol, which is completely renewable, and which is made from lingo-cellulose, is used for the testing of a spark ignition engine.**

In this paper, engine performance and emission parameters of single cylinder 4-stroke SI engine have been experimentally studied at various compression ratios (CRs) for petrol and petrol/n-butanol blends in a broad range of applied load without any tuning and modification of the engine. The performance parameters such as brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) have been evaluated for petrol and blends of petrol/n-butanol such as B0 (100% petrol), B5 (95% petrol + 5% n-butanol by volume), B10, B15, B20 and B25 at compression ratios of 4.67:1, 6:1 and 8:1. Similarly emission parameters for CO, CO_2, HC and NO_x have also been evaluated and analysed. Results of study show that, the BTE increases and BSFC reduces when blend of n-butanol is used, as a result of proper fuel combustion and higher oxygen content. As the compression ratio increased, the BTE also increased by 18.63% and by adding 25% n-butanol, it increased by 23.24%. The emissions of Carbon monoxide (CO), Carbon dioxide (CO_2), Hydro Carbons (HC) and Nitrogen oxides (NO_x) were also found reduced by 92.18%, 23%, 38.14% and 18.29% respectively with the fuel B25 at a CR of 6:1 as compared with those of petrol at original CR.

Key Words: **SI engine, compression ratio, n-butanol, performance and emission characteristics.**

1. INTRODUCTION

Presently, most of our energy demands are met by fossil fuels. The reserves of these fossil fuels are limited and will be depleted soon, if the consumption keeps rising at the current rate. The population growth and technological development of the developing countries are the major reasons for increasing demands of energy. The production and use of these fuels, impact the environment negatively, and therefore this aspect is important and cannot be easily ignored. The demands of renewable fuel have been increasing as a result of increasing cost of fossil fuels [1].

Energy diversity is noted to be a vibrant factor for commercial growth coupled with environmental sustainability, and for this reason efforts are needed to search for potential alternates [2]. These alternative fuels should be obtained from renewable resources and should be used directly in the engine without modifying the structure of the engine [3]. Emissions are generated as by-products from combustion of fuel in engines. The main emissions from engines are HC, CO, CO_2 and NO_x and some amount of formaldehyde and particulate matters. As a compound hydrocarbon, petrol is a particularly polluting fuel [4].

Spark ignition engines are widely utilized in the two/three wheeler vehicles, light motor vehicles, sports utility vehicles, small water pump sets, as a vibrator, small electricity generator set ups etc. The SI engine used for this research has been manufactured by Crompton Greaves. It has a total displacement of 256 CC and compression ratio of 4.67: 1. The motive of this research is to compare engine performance and emission parameters for different blends of n-butanol and petrol to determine the most suitable blend and compression ratio.

In the fuel categories of the spark ignition engine, alcohol is one of the fuel additives which improves antiknock characteristics with a reduction of HC and CO emissions [5]. Alcohols contain oxygen in the hydroxyl group (-OH), which promotes proper combustion. The combustion rate of alcohols is faster than petrol. Also alcohols are free from elements like sulphur and phosphorus, thus creating less polluting oxides.

Butanol is also an attractive alternative fuel. Butanol has more energy content viz. 30% greater than ethanol and is closer to petrol in calorific value. Butanol can be obtained as a biomass-based renewable fuel by fermentation. The physical and chemical properties of petrol and n-butanol are shown in Table 1

Table 1: Physical and chemical properties of Petrol and n-butanol

Property	Petrol	n-Butanol
Chemical formula	C_4H_9OH	C_4H_9OH
Molecular weight	95-120	74.12
Composition by weight-%		
Carbon	84	65
Hydrogen	16	13.5
Oxygen	0	21.5
Viscosity (mm^2/s) at 40°C	0.8	2.63
Boiling point or range °C	25 - 215	118
Latent heat of vaporization kJ/kg	380 - 500	716
Density (kg/m3) at 28°C	740	810
Lower calorific value (kJ/kg)	44200	33100
Stoichiometric Air/fuel ratio	14.7	11.2
Self-ignition temperature °C	250-450	300 - 385
Octane number	91	87

Thermal efficiency of an engine can be improved by increasing the compression ratio, thus producing more power output. Also, the thermal efficiency and brake power varies with various loads and speed ranges. However, there is a limitation for increasing the compression ratio because of knocking.

Aina et al. [6] reported that the BSFC decreases by 7.75%, while brake power and BTE was found improved by 1.34% and 8.49% respectively with increase in the compression ratio of SI engine with petrol as a fuel. **Celik et al.** [7] revealed that with methanol, the BSFC values were greater than with petrol at all the compression ratios. The BTE and engine power were increased by 36% and 14% while CR was increased from 6:1 to 10:1. On the other hand, CO, CO_2 and NO_x emissions decreased by 37%, 30% and 22% respectively. **Celik** [8] also reported that at a CR of 6:1, brake power increases with increasing volume of ethanol in petrol. Increments in power of around 3%, 6% and 2% were achieved with E25 (25% Ethanol + 75% petrol by volume), E50 and E75 fuels respectively. **Koç et al.** [3] reported that there was an increment in engine torque of 2% with E50 and E85 at CR 10.0:1 and about 2.3% and 2.8% respectively with E50 and E85 at CR 11.0:1 as compared with E0 at test CRs. **Balki & Sayin** [9] stated that at original CR, the BTE increased about 4.51% with methanol and 3.65% with ethanol. At CR of 9.5:1, ethanol and methanol produced maximum BTEs of about 30.22% and 30.47% respectively, and petrol produced a maximum BTE of 29.73% at 9.0:1 CR. Emission parameters like CO, HC, CO_2 and NO_x were improved compared with petrol. **Canakci et al.** [2] reported that the BSFC was increased by 0.6% 3.3%, 2.8% and 3.6%, with M5, M10, E5 and E10 respectively, in comparison to pure petrol at a speed 80km/h. However, at a speed of 100km/h, the BSFC was found to decrease as compared with that at speed 80km/h. **Elfasakhany** [10] reported that using petrol, the exhaust emissions were greater by 32%, 43% and 26% for CO, CO_2 and HC respectively compared to the butanol fuel blends. **Deng et al.** [11] stated that at optimum ignition timing, with addition of butanol, improved results were obtained for energy consumption, brake power and CO & HC emissions except NO_x emissions. **Gu et al.** [12] revealed that the BSFC was higher with B10 (10% n-butanol + 90% petrol by volume), B30, B40 and B100 than those of petrol because of butanol have lower heating value while emission parameters were improved. **Feng et al.** [13] stated that with the addition of H_2O with B35, the increment of 1.2% were found in torque, decrement of 11.5% in BSFC. The emissions of HC and CO were found decreased by 11.8% and 13.8% respectively, while NO_x and CO_2 emissions were found increased by 38.3% and 7.7% respectively. **Venugopal & Ramesh** [14] reported that BTE was lower with the blends of B60, B80 and B100 because of higher fraction of butanol in the blends. **Jin et al.** [15] stated that when the butanol content was below 40%, the change in BSFC was only around 10%. **Siwale et al.** [16] reported that withincrease in Brake Mean Effective Pressure (BMEP), BTE was increased at all pressures. Higher BTE was obtained with the blend M70 at all pressures. For all blends, BSFC was greater than that of petrol and BMEP decreased with increase in pressure. **Sayin & Balki** [17] revealed that the negative results of iso-butanol on BSFC were recovered on increasing CR. 13% difference was obtained in BSFC, between engine running on CR 9:1 and CR 11:1, as compared with engine running on petrol at test CRs. There was also an increment in BTE of 2.34%, 5.54%, and 49.91% with B10, B30 and B50 respectively compared to B0.

2. MATERIALS & METHODS

For testing, a single cylinder, 4-stroke, SI engine with an original CR of 4.67 was selected. Although originally manufactured by Greaves, the test rig was modified by Technical Teaching (D) Equipments, Bangalore, India. Table 2 shows the specification of the engine test rig. The cylinder head is replaced by an auxiliary head for changing the compression ratio. The variation in the clearance volume is done by the piston mounted in the auxiliary cylinder head. By lowering or raising this piston, the clearance volume can be decreased or increased respectively. Figure 1 represents a schematic diagram of the engine test rig.

Eddy current dynamometer is provided for applying the load. For data acquisition and computer interfacing, a data logger is provided for collection of data and calculation of different engine performance characteristics. The system uses NI6210 high speed data logging card from National Instruments India, having a capability of logging 250 KS/sec. Sensors are mounted at key locations for measurement of temperature, in-cylinder pressure, speed, water flow rate, air flow rate and fuel flow rate. A 5 gas analyser manufactured by Indus Scientific Pvt. Ltd. and certified by Automotive Research Association of India (ARAI) is used to evaluate the emission parameters of the engine.

Various tests were performed at different loads with different blends of petrol and n-butanol with different compression ratios. The blends that were used have been labelled as B5 (5% n-butanol by volume + 95% petrol by volume), B10, B15, B20, & B25. The compression ratios used were 4.67:1 (original CR), 6:1 and 8:1. Properties of fuel blends used for the calculation of the performance characteristics were calculated and are listed in Table 3.

Table 2: Specification of the engine test rig

Make & Model	Greaves Cotton & MK-25
Fuel	Petrol (Petrol)
No. of Cylinders	1
Bore x Stroke (mm)	70 x 66.7
Clearance Volume (CC)	54.8
Total Displacement (CC)	256
Compression ratio	4.67:1
Rated Power	2.2 kW/ 3 HP @ 3000 rpm
Ignition Timing	28 Deg. BTDC

When the engine was run at a CR of 9:1 with petrol, the cylinder pressure was observed to rise to 110 bar. The engine became very noisy and started to vibrate heavily. It was concluded that these conditions represented the adverse phenomenon of detonation occurring in the engine. Owing to this, the tests were conducted at a reduced CR of 8:1.

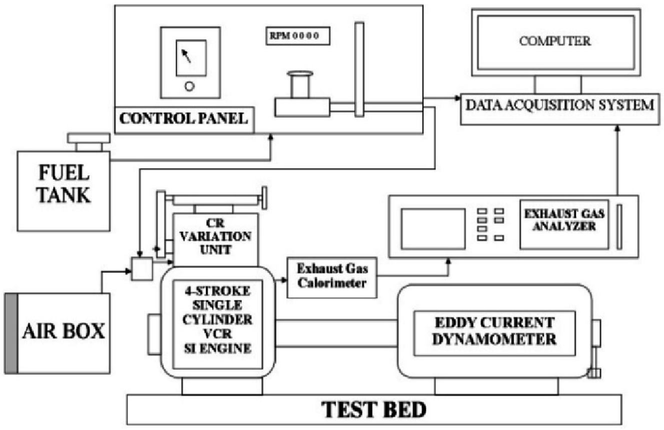

Figure 1: Schematic diagram of engine test rig

The engine speed was governed by a governor, and all tests were conducted with wide open throttle (WOT). For a particular test condition, readings of engine performance and emission characteristics were taken after duration of 15 minutes of uninterrupted running. The data represented in the results & discussions section are for full load only.

Table 3: Calculated properties of the fuel blends

Property	Petrol	n-Butanol	B5	B10	B15	B20	B25
Density (kg/m3) at 28°C	740	810	744	747	751	754	758
Lower calorific value (kJ/kg)	44200	33100	43645	43090	42535	41980	41425

In this study, the characteristics selected for performance measurement are BTE and BSFC. CO, CO_2, HC and NO_x emissions have been considered for emission measurement.

3. RESULTS & DISCUSSIONS

3.1. PERFORMANCE CHARACTERISTICS

3.1.1. Effect of n-butanol blends and CRs on BTE

Figure 2 shows the comparison of BTE for engine running with different test fuels at CRs of 4.67:1, 6:1 and 8:1 at full load. As the quantity of n-butanol is increased from 0 to 25 percent in the petrol; BTE is found to increase. This is due to proper combustion of the air/fuel mixture in the combustion chamber as n-butanol contains higher oxygen content and when the compression ratio increases, BTE also increases due to the fact that n-butanol has high latent heat of vaporization. Therefore, during vaporization in the compression stroke, n-butanol absorbs additional heat from the cylinder wall. Due to this, the work spent to compress the air-fuel mixture is reduced which results in an increase in thermal efficiency. When the BTE of these test fuels were compared with neat petrol at original CR, it was found to increase by 13.96% with test fuel of B20 at CR 4.67:1; 23.24% with B25 at CR 6:1; and 23.16% with B25 at CR 8:1. Maximum efficiency was obtained for the test fuel of B25 at CR of 6:1.

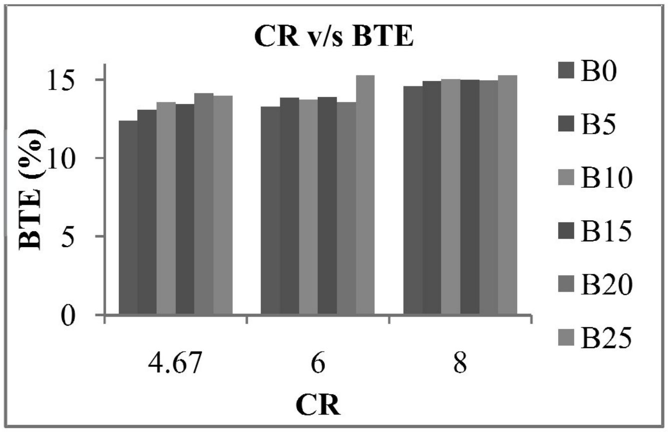

Figure 2: Comparison of BTE for fuel blends at different CR

3.1.2. Effect of n-butanol blends and CRs on BSFC

The variation in BSFC for all test fuels with increasing CRs is shown in Figure 3. BSFC of all test fuels was compared with that of neat petrol at original CR (4.67:1). For example, it can be observed from figure 3 that in comparison to neat petrol at original CR, BSFC of B15 (at CR 4.67:1), B25 (at CR 6:1) and B25 (at CR 8:1) show reductions of 14.92%, 13.43% and 14.92% respectively. This is a result of the higher density of n-butanol and proper burning of the fuel because of higher oxygen content.

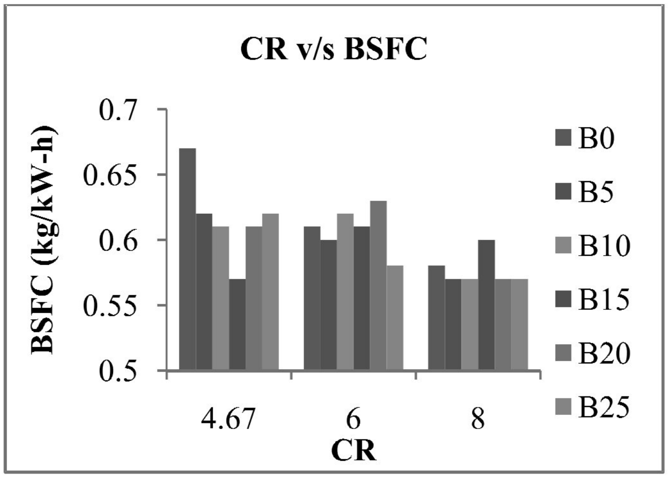

Figure 3: Comparison of BSFC for fuel blends at different CR

3.2. EMISSION CHARACTERISTICS

3.2.1. Effect of n-butanol blends and CRs on CO emissions

CO emission is greatly dependent upon the air-fuel ratio. At higher CRs, more homogeneous mixtures are formed and hence proper combustion of the fuel is made. As the quantity of n-butanol is increased in blended fuels, oxygen content also increases. The formation of CO depends upon concentration of oxygen. As the concentration of oxygen is increased, carbon monoxide can oxidize and form CO_2. Higher combustion efficiency also causes the reduced emissions of CO. Figure 4 shows the variation of CO emission with increasing CR for all test fuels. For example, it can be observed that the emissions are decreased by 89.11% for B25 test fuel at CR 4.67:1, 92.18% for B25 fuel at CR 6:1 and 86.53% for test fuel of B25 at CR 8:1. This is due to the fact that n-Butanol has lower carbon content. The minimum emissions of CO exhausted from the engine are observed by B25 test fuel at CR 6:1.

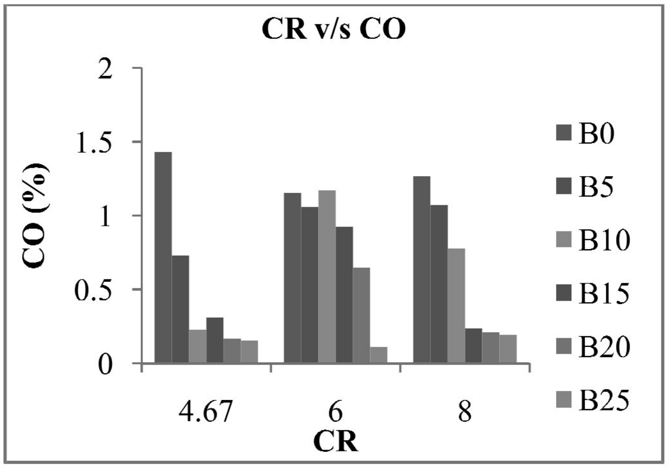

Figure 4: Comparison of CO emissions for fuel blends at different CR

3.2.2. Effect of n-butanol blends and CRs on CO_2 emissions

Figure 5 represents the variation in CO_2 with respect to increasing CR for all test fuels. CO and CO_2 have opposite correlation, i.e., as CO increases, CO_2 decreases. As the alcohols have lower Carbon content and Carbon/Hydrogen (C/H) proportion than petrol, CO_2 emissions are low for alcohols. The decrease in CO emissions leads to increase in the formation of CO_2. The emissions of CO_2 are decreased at all test CRs when compared with those of petrol. For example, it can be inferred from figure 5 that CO_2 emissions are reduced by 25.93% with test fuel of B20 at CR 4.67:1, 28.15% with B20 at CR 6:1 and 27.79% with B20 at CR 8:1. The engine emits minimum CO_2 with the fuel of B20 at CR 6:1.

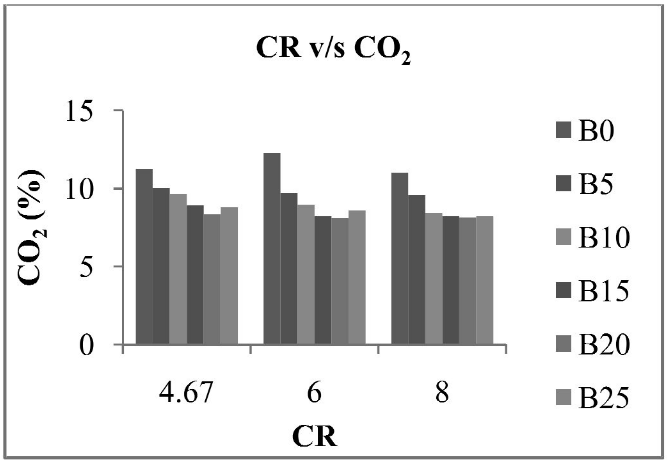

Figure 5: Comparison of CO_2 emissions for fuel blends at different CR

3.2.3. Effect of n-butanol blends and CRs on HC emissions

The variation in the HC emissions for all test fuels with increasing CRs are shown in Figure 6. The fuel blends emit low HC due to lower C/H ratio of n-butanol. The UHC layers are formed because of quenching of flame by the cold surface of walls of the combustion chamber. As the load increases, temperature of the combustion chamber increases, thus resulting in the reduction of UHCs. Again, as can be observed from figure 6, HC emissions are reduced by 51.28% with test fuel of B20 at CR 4.67:1, 38.14% with B25 at CR 6:1 and 32.69% with B25 at CR 8:1 when compared with those of petrol at original CR. It can also be observed that as the compression ratio increases, HC emissions are also increased. This is because the surface/volume ratio increases with increasing CR, thus resulting in the flame cooling at places near the cylinder surface, causing misfire. Minimum emissions of HC were observed for the test fuel B20 at CR 4.67:1.

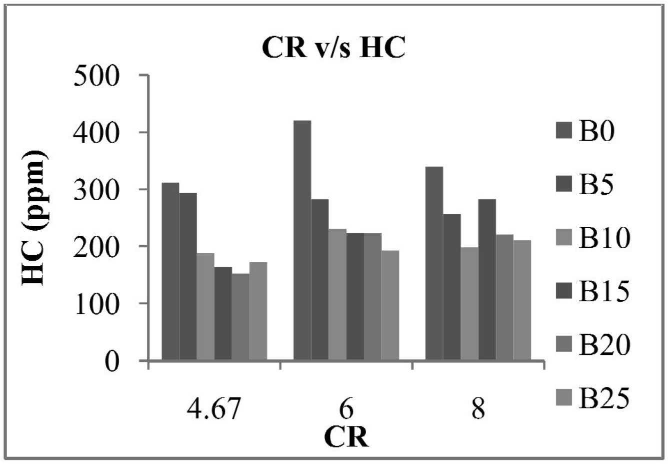

Figure 6: Comparison of HC emissions for fuel blends at different CR

3.2.4. Effect of n-butanol blends and CRs on NO_x emissions

Figure 7 shows the variation in NO_x emissions for all test fuels with increasing CR. The rate of formation of NO_x depends on the temperature. At higher temperature, nitrogen molecules present in the air combine with the oxygen molecules and form oxides of nitrogen. As the load increases, more fuel burns, and the temperature of cylinder rises, resulting in increased NO_x formation. With increased proportion of n-butanol in the blend, the cylinder temperature reduces due to higher heat of vaporization of n-butanol, resulting in reduced formation of NO_x. On comparing the NO_x emissions, it was observed that the NO_x is reduced by 30.09% with B25 test fuel at CR 4.67:1, 18.29% with B25 at CR 6:1 and 6.76% with B20 at CR 8:1.

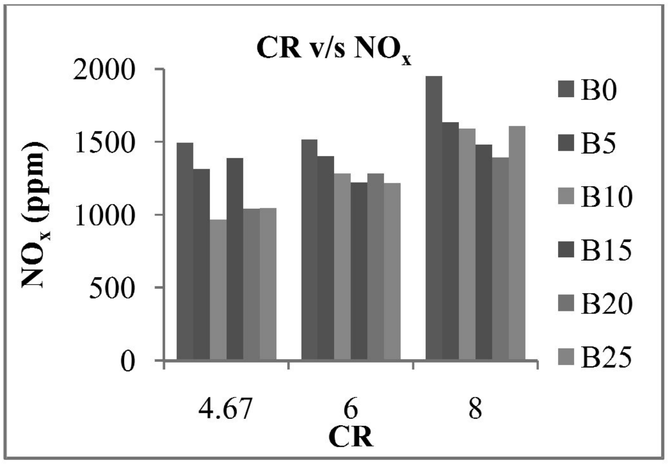

Figure 7: Comparison of NO_x emissions for fuel blends at different CR

4. CONCLUSIONS & FUTURE SCOPE

In this experimental study, a single cylinder 4-stroke SI engine was operated with the different test fuels: B0, B5, B10, B15, B20 and B25 at compression ratios of 4.67:1, 6:1 and 8:1. The performance and emission parameters of the engine were measured, compared and analysed. The following observations were made after conducting the tests:

1. The best performance and emission characteristics were observed with test fuel B25 at CR 6:1.
2. The BTE of engine was observed to rise by 13.96% with petrol at full load when the CR was increased to 8:1. However, with a blend of 25% n-butanol in petrol, the BTE was found to increase by 23.24% at CR 6:1.
3. In case of BSFC, a reverse trend was found. Due to higher density and oxygenated n-butanol, BSFC of B25 was found to reduce by 13.43% at CR of 6:1 compared to BSFC of petrol at original CR.
4. CO and CO_2 emissions in case of petrol were found higher compared to blends of n-butanol. At original CR, test fuel of B25 gave 89.11% reduced emissions of CO from petrol fuel. 92.18% reduced emissions of CO were obtained for B25 at CR 6:1 compared to that of petrol at original CR.
5. Blending with alcohol was found to have a positive impact on UHC formation too; as emissions of HC in the case of B25 were found to be reduced by 38.14% at CR of 6:1 compared to that of petrol at original CR.
6. NO_x emissions from the engine running with petrol at original CR exhausted 1492 ppm. With increasing CR, NO_x emissions were also found to increase. However, with a blend of 25% n-butanol in petrol, NO_x emissions at an engine CR of 6:1 were found to be 1219 ppm, which is 18.29% lower compared to that of petrol at original CR.

7. As a part of furthering this research work, many more possible blends of petrol and alcohols can be prepared and tested at different CRs. Apart from this, the effects of Exhaust Gas Recirculation (EGR) can also be tested in conjunction with the existing line of work.

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