Investigation of engine characteristics of a variable compression ratio diesel engine using biodiesel and alcohol blends

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Abstract. Increasing environmental pollution and reducing fossil fuels are major concerns of today’s age. To address both the above said issues, the present research focuses on fossil fuel compensation with Biofuels additives. The objective is to analyze combined effect of biodiesel, alcohols and other additives on the diesel engine performance and emission characteristics. The prime target of present research is to analyze the emission characteristics of the diesel engine fueled with Biodiesel (20%)-diesel, Biodiesel (20%)-ethanol (10%)-diesel and Biodiesel (20%)-butanol (10%)-diesel blends. For this purpose, various loads and compression ratios have been applied on each of the blends, to get the optimum result for better performance and reduction in emissions. Engine tests were conducted at variable loads, starting from no load (0 Kg) to full load (15 Kg) at rpm of 1500 on a single cylinder diesel engine. Two compression ratios CR16 and CR18 were used for the research. Engine performance parameters namely BSFC, BTE and engine emissions namely NOx, CO, HC and CO2 were measured. Performance and emission variations of the modified blends were compared with the reference fuel (pure diesel) for the quantitative assessment of the improvements.

1. Introduction
The reserves of the fossil fuels are diminishing in an incredible pace. So, designers and researchers are finding distinctive strategies to optimize the fuel efficiency and to diminish the problem of carbon emissions. As per an estimate, the fossil fuel reserves will last for 60 years for natural gas, 40 years for oil and 218 years for coal [1, 2].

Also, concerns for the environment have significantly increased throughout the world over the last few decades. Due to excessive use of fossil fuels, various environmental changes are taking place globally such as ozone layer depletion, greenhouse effect, climate changes, acid rain etc. So, scientists throughout the world realized that, something constructive need to be done soon to reduce the Greenhouse Gas and toxic emissions such as carbon monoxide, carbon dioxide, oxides of nitrogen, hydrocarbons and particulate matter. Various types of alternative fuels like bio ethanol, biodiesel, hydrogen, LPG have been proposed by researchers and engineers. These fuels are substitute to the crude oil, so they are considered to be very important fuels.

Among all the alternative fuels available to the customers in India, only two most importantly used are ethanol, in the form of ethanol-gasoline blends and biodiesel, in the form of diesel-biodiesel blends. In compression ignition engines, biodiesel became popular due to its various advantages and benefits
in terms of curbing emissions from the engines. But neat biodiesel and biodiesel blends with high percentage can cause a number of engine performance issues, including injector choking, fuel filter plugging, elastomer seal hardening and cracking, piston ring sticking and breaking, and engine lubricant dilution and degradation. Hence, blending with diesel is the best option to conserve fossil fuels as well as for reducing emissions from C.I engine [3-5].

Low energy content, low cetane number, decreased flash point, worse miscibility, higher volatility and worsened lubricity prevent ethanol from being used as a fuel in diesel engines. One of the best alternatives to ethanol is butanol. Butanol releases more energy per unit mass, is less evaporative and has a lower auto-ignition temperature. It has higher calorific value, higher cetane number, and improved lubricating ability compared to methanol and ethanol. It is highly miscible with diesel, FAME and vegetable oils and it is less corrosive. When mixed with diesel or FAME slightly increases specific fuel consumption. It was found that Diesel- butanol-FAME blend lowers the cetane number and viscosity of the blend with increase in the butanol content. Also, the specific fuel consumption increases with the use of these blends and the harmful emissions (CO, Particulate matter, soot) are reduced. Combustion temperature gets lowered by FAME-Butanol blends and hence both soot and NO\textsubscript{x} emissions also reduce [6, 7].

2. Experiment
The experiment comprises of selection and collection of plant’s seed for the oil after treatment with quenching agents with determination of extraction method.

2.1 Materials
Ethanol, 1-Butanol, were purchased from the local chemical supplier in the city beautiful, Chandigarh. Soyabean biodiesel (FAME) was purchased from Agroprocessor ltd. (Nagpur, India). Petrodiesel (Indian Oil Corporation) was obtained from a local petrol pump.

2.2 Preparation of Blends
Four fuels of 1.5 litres each were prepared in the chemical laboratory as engine needs minimum of 1.5 litres fuel for performing tests. For Blend 1 (BD), 300 ml (20%) of biodiesel and 1200 ml (80%) of diesel were mixed. For Blend 2 (BbuD), 300 ml (20%) of biodiesel, 150 ml (10%) of ethanol and 1050 ml (80%) of diesel were mixed. For Blend 3 (BED), 300 ml (20%) of biodiesel, 150 ml (10%) of butanol and 1050 ml (80%) of diesel were mixed. Fuels are shown in the Figure-1.

![Figure 1. Diesel and its blends with biodiesel and alcohol](image)

After making blends, fuel properties such as density and calorific values were measured using CCD 13 – Density Meter and bomb calorimeter respectively. These values are required to be input in the performance prediction software used in the engine. Fuel properties of the various test fuels used in this study are given in Table-1.
Table 1. Fuel properties of the blends

| Fuel                           | HHV (KJ/kg) | Density @ 15 °C |
|--------------------------------|-------------|-----------------|
| Diesel (100%)                  | 45500       | 832             |
| Biodiesel (20%)                | 44296       | 843             |
| Biodiesel (20%) Ethanol (10%)  | 42730       | 838             |
| Biodiesel (20%) Butanol (10%)  | 43480       | 840             |

2.3 Experimental set-up

Engine used for the experimentation was single cylinder, four stroke, and variable compression ratio direct injection diesel engine. Tilting block arrangement was used to change the compression ratio. Engine test rig was connected to eddy current dynamometer and load cell was used for changing load with the help of dynamometer. Cooling water was supplied with the help of two rotameters for calorimeter and cylinder head water flow measurement. The technical specifications of the engine are given in Table-2.

Table 2. Specifications of the engine

| Model       | TV1       |
|-------------|-----------|
| Make        | Kirloskar Engine |
| Type        | Water cooled , Four stroke, diesel |
| No. of cylinder | single   |
| Bore        | 87.5 mm  |
| Stroke      | 110 mm   |
| Combustion principle | C.I     |
| Capacity    | .661 litres |
| Peak pressure | 77.5 kg/cm² |
| Fuel timing for std. engine | 23° BTDC |
Fuel line pressure and Combustion pressure were measured by two piezometric sensors that were fitted on fuel injector and cylinder head respectively. The setup consists of an air box, manometer, fuel tank, and central processing unit. The Data acquisition device made by national instrument was connected to the computer and all the signals were transmitted to the software ‘Enginesoft LV Version 9.0’ (Apex Innovation Pvt. Ltd). AVL DI Gas 444 Analyzer (India) was used for performing the exhaust gas analysis. The exhaust gases namely CO, CO₂, HC, and NOₓ were analyzed. Figure-2 shows the Engine Layout.

2.4 Experimental procedure
To validate the fact that CR has impact upon Emissions, CR16 and CR18 were used as compression ratios for various Biodiesel-alcohol blends. Then, comparative analysis with Variable Compression Ratio Diesel engine was conducted at standard specifications.

The initial test was done with pure diesel followed by BD, BED and BbuD at both compression ratios. During the measurement engine was tested with no load followed by 20%, 40%, 60%, 80%, and 100% load conditions. Output readings of in-cylinder pressure, temperatures, engine speed, air flow rate, fuel flow rate, and fuel line pressure were automatically recorded by the engine software (Enginesoft LV Version 9.0) and engine software used these values for the generation of the performance parameters.

Among the emission characteristics NOₓ, CO, HC and CO₂ were measured and among the performance characteristics namely brake thermal efficiency and brake specific fuel consumption were measured.

3. Results and Discussions – Emission Characteristics
3.1 Carbon monoxide (CO)
CO emission is a result of incomplete combustion and slow burning of the soot during final combustion phase. CO emissions reduced as the load increased and this trend was due to the increase in combustion temperature which leads to increased complete combustion at higher loads [8].

From the Figures-3 (a)/ (b) it has been shown that, with the presence of biodiesel in the fuel, CO emissions of blend decrease due to increase in the oxygen content and lower carbon to hydrogen ratio as compared to pure diesel [15]. Biodiesel has a higher cetane number, which results in the lower possibility of formation of rich fuel zone and thus reduces CO emissions [8].
3.2 Carbon Dioxide (CO2)

The CO2 emissions variation with engine load has been depicted in Figure- 4 (a)/(b). The steady increase in CO2 emissions trend with constant increase in the engine load for all the test fuels has shown that the combustion was more complete and effective at higher loads. CO2, being the byproduct of complete combustion of CO and HC, always increases with the more oxidation of CO and HC. This increase of CO2 concentration in the exhaust indicates that the proper combustion of fuel has occurred in the combustion chamber of the engine [20].

At CR16, the CO2 emission for biodiesel and alcohol blended fuels was higher than the diesel as they are oxygenated fuels i.e. they carry high oxygen content thus more amount of CO2 was produced as combustion byproduct as shown in the Figure- 4(a). However, the higher carbon dioxide emissions is a matter of less concern because it is recovered by the nature cycle for biodiesel crops, as previously suggested by many authors [8]. But at full load, Blend 1 resulted in lower CO2 emissions than diesel. Biodiesel is a low carbon fuel as compared to pure diesel. During complete combustion due to the lower carbon to hydrogen ratio dominates the effect of increased oxygen content thus reducing the CO2 emissions at full load [8].

The CO2 emission behaviour at CR-18 for all loads is quite similar to that at CR-16 except for biodiesel blended fuel where CO2 emissions are lower than diesel at low loads of upto 40%. Another exception was for Blend 3, where in spite of ethanol carrying additional oxygen, Blend 3 is having lower CO2 emissions than Blend 2 at lower loads of up to 40%.

**Figure 3.** (a) CO vs Load at CR16; (b) CO vs Load at CR18
The effect increase or decrease in CO$_2$ emission is dependent upon the presence of oxygen content and carbon to hydrogen ratio. Biodiesel, ethanol and butanol are oxygenated blends and have lower carbon-hydrogen ratio as compared to diesel. If effect of oxygenated nature of blend dominates the lower carbon-hydrogen ratio effect, then CO$_2$ emission tends to increase. But if effect of lower carbon to hydrogen ratio dominates the increased oxygen effect, then CO$_2$ emission for the blend tends to decrease [8], [21].

### 3.3 Oxides of Nitrogen

With the constant increase in the load the overall air-fuel ratio decreased which resulted in the higher adiabatic flame temperature of the gases inside the cylinder and this led to increase in NO$_x$ formation, as also stated by Xue et al [8]. Same reason for this trend was explained by Sehmus et al [12], that NO$_x$ emissions increased with the increase of the engine load for all fuels. This was due to the higher combustion temperature inside the cylinder, as greater amount of fuel is burnt at higher loads. Also, NO$_x$ levels obtained at CR16 are lower as compared to CR18. This reduction had been mainly caused by the incomplete combustion at low cylinder pressure at CR16. At CR16 all the oxygenated blends showed more NO$_x$ emissions as compared to diesel fuel as shown in Figure 5(a). It is due to the fuel borne oxygen present in the blended fuels [8].

Also, NO$_x$ levels obtained at CR16 are lower as compared to CR18. This reduction had been mainly caused by the incomplete combustion at low cylinder pressure at CR16. It is due to the fuel borne oxygen present in the blended fuels.

A possible reasoning for lower NO$_x$ emissions Blend 2 (Biodiesel-Butanol-Diesel) as compared to Blend 1 (Biodiesel-Diesel) can be attributed to lower calorific value of butanol leading to lower combustion temperature as stated by G.Tuccar [16]. S. Imtenan et al [13] also stated the same reasoning. At lower loads for CR18, NO$_x$ emissions increased for Blend 2 as compared to biodiesel showing the dominating effect of lower cetane number and thus longer ignition delay, leading to higher combustion temperature as stated by G.Tuccar [16].
Figure 5. (a) NOX vs Load at CR16; (b) NOX vs Load at CR18

Possible explanation for the highest NOX emissions by Blend 3 i.e. Biodiesel-Ethanol-Diesel blend as shown in Figures- 5 (a)/(b) can be attributed to the highest percentage of oxygen present in ethanol, leading to fuel dilution, hence leaner fuel leading to higher combustion temperature thus maximizing the NOX levels. The reason for this can be attributed to the highest percentage of oxygen present in ethanol, leading to fuel dilution, hence leaner fuel leading to higher combustion temperature thus maximizing the NOX levels. The same logical reasoning was also stated by S. Imtenan [13].

4. Conclusions

Following conclusions can be drawn from this research work:

- In general, CO emissions reduced for all the fuels with the increase in load. With respect to pure diesel, all blends exhibited lower CO emissions. Blend 1 (BD), Blend 2 (BbuD) and Blend 3 (BED) shows maximum CO reduction of 33.3%, 50% and 66.67% respectively with respect to pure diesel at Compression Ratio 16 and 50%, 50% and 66.67% respectively at Compression Ratio 18. Also, Blend 2 (BbuD) and Blend 3 (BED) showed even lower CO emissions as compared to Blend 1 (BD). Blend 2 (BbuD) and Blend 3 (BED) shows maximum reduction of 33.3% and 50% respectively at both compression ratios, in comparison with the Blend 1 (BD).

- In general, CO2 emissions increased for all fuels with increase in load. With respect to pure diesel, all Blends exhibited higher CO2 emissions. Blend 1 (BD), Blend 2 (BbuD) and Blend 3 (BED) showed maximum CO2 increase of 15.4%, 23% and 23% respectively at Compression Ratio 16 and 13.3%, 18.7% and 25% respectively at CR18 with respect to pure diesel. Though Blend 2 (BbuD) and Blend 3 (BED) have showed higher CO2 emissions as compared to Blend 1 (BD). But among the Blend 2 (BbuD) and Blend 3 (BED), Blend 2 has shown a maximum of 12.5% and 11% reduction in CO2 emissions at Compression Ratio 16 and Compression Ratio 18 respectively with respect to Blend 3.

- In general, NOX emissions increased for all fuels with increase in load. Blend 1 (BD), Blend 2 (BbuD) and Blend 3 (BED) showed maximum increase of 33.3%, 13.5 and 26.7% respectively
at Compression Ratio 16 and 14.5%, 17.3% and 28.9% respectively at CR 18 with respect to pure diesel.

Among the blended fuels, Blend 3 (BED) showed higher NOx emissions (Maximum increase-38%), whereas Blend 2 (BbuD) showed lower NOx emissions (Maximum reduction-25%) with respect to Blend 1(BD). Blend 2 (BbuD) shows average reduction of 16.52% and 12.08% with respect to Blend 3 (BED) at Compression Ratio 16 and Compression Ratio 18 respectively.

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