Improvement in performance and combustion of CRDI engine with simarouba blended fuel as alternative fuel

V. Mathan Raj⁺, Akshay Manojᵇ

⁺School of mechanical Engineering, Kattankulathur, 603203
ᵇSchool of mechanical Engineering, Kattankulathur, 603203

Email: mathanrv@srmist.ac.in

Abstract. This paper is concerned with the benefits of addition of 1-pentanol and benzyl alcohol, which are classified as aliphatic and aromatic type alcohols respectively based on the position of hydroxyl group, to a blend of Siarouba glauca and diesel (B20) in minor quantities. This was later tested under various load conditions to study the performance, emission, and combustion on a CRDI engine. Literature is cited to show that the poor performance of B20 can be enhanced substantially by the addition of 1-pentanol (P) and benzyl alcohol (Bn). Each sample of fuel was prepared by 5% concentration by volume addition of 1-pentanol and benzyl alcohol. The tests were conducted on a single-cylinder, four-stroke, and constant speed CRDI engine and compared with the results from which diesel was used as a fuel. Break thermal (BT) efficiency is found to be a considerable 9.08% and 5.5% more in 5% pentanol and 5% Benzyl Alcohol fuel blends respectively than that of diesel. While comparing brake specific fuel consumption (BSFC) it was found that diesel has a noticeable 24.32% more consumption rate than both the fuel types. The emission rate of CO was found to be 81.25% and 81.33% less with 5% pentanol and 5% Benzyl Alcohol fuel blends than that of diesel. Diesel also released .5714 and .2698 times more Hydrocarbon (HC) compared to 5% pentanol and 5% Benzyl Alcohol respectively. However, NOx emissions were higher in both 5% pentanol and 5% Benzyl Alcohol. These benefits are documented by comparing each fuel in different load conditions and are represented graphically.

1. Introduction

Thus far, most of the investigations have been based on finding an alternate source of fuel instead of diesel. Although, alternate sources like biomass-derived fuels (straight vegetable oil) have gained much attention particularly because they can be utilized directly without modifying the existing engine structure, they were unable to match the efficiency and power output of the diesel. They also faced a lot of problems like poor combustion along with long-term problems like piston ring sticking and injector clogging. This study uses Simarouba glauca (paradise oil) seed oil as the straight vegetable oil. Simarouba glauca and diesel blend (B20) were prepared and tested to study the CRDI engine performance, emission, and combustion characteristics under different load conditions. To each of the fuel samples prepared for B20, 1-pentanol and benzyl alcohol additives were added at 5% concentration.
by volume. Experimental tests for the different fuels were performed in a single-cylinder, four-stroke, and constant speed CRDI engine, and the engine characteristics were compared with diesel. Some specific potential benefits accruable from using this as a fuel are:

a) Better performance with increase of alcohol content in the B20 blend.
b) Higher HC, CO, and smoke emissions associated with B20 blend fuel are reduced with alcohol addition.
c) NO emissions could be reduced with the addition of alcohol blends and 1-pentanol shows more promising results in terms of low NO emissions compared to benzyl alcohol.

1.1 SIMAROUBA OIL

Simarouba is a genus of trees and shrubs in the family Simaroubaceae, native to the neotropics. It grows well in degraded land and adapts well to various temperature zones. Since there is an ample amount of degraded land, Simarouba can be cultivated in large quantities. This can help in overcoming the oil shortage and the economic feasibility. The oil was produced through a two-stage esterification process using concentrated sulphuric acid and sodium hydroxide as catalysts. Simarouba glauca seed oil biodiesel was blended with diesel in various proportions, and its thermo-physical properties were characterized by chromatographic and spectroscopic techniques. Moreover, the performance and emission characteristics were evaluated in a single-cylinder direct injection diesel engine. The free fatty acid content of the oil was reduced from 3.5 to 0.2%. Simarouba glauca seed oil (SGO) is having a good potential of replacing diesel soon.

1.2 TRANSESTERIFICATION PROCESS

Transesterification is the process of exchanging the group R” of an ester with the organic group R’ of alcohol. This reaction can be catalysed by the addition of an acids, bases or enzymes (biocatalysts) like lipases. Biodiesel production is the process of producing the biofuel, biodiesel, through the chemical reactions of transesterification and esterification. This involves vegetable or animal fats and oils being reacted with short-chain alcohol. It is better to use an alcohol of low molecular weight. Even though methanol is preferable, ethanol is used due to its lower cost. In this study ’n-pentanol and o-benzyl alcohol’ have been used to study the performance of higher derivative alcohol as well as the stability of structure provided by the aromatic alcohol.

2. Literature Survey

Sharma P and Dhar A showed that the stability improves, and combustion noise reduces with hydrogen increase in fuel and that lower level of hydrogen substitution reduced unregulated emissions at all loads in [1]. Saravanan CG, Kiran KR, Vikneswaran M and Rajakrishnamoorthy P explained that the blending ratios of pine oil biodiesel can be extended with high injection pressure strategies. Shahir VK, Jawahar CP, Vinod V and Suresh PR. specified that the tyre oil while it used at an optimum blend, is an important option as a fuel for diesel engines based on CRDI technology. Another important conclusion is that the fuel is suitable to use in the CI engine without any major change in the engine. The exhaust gas temperature and BSFC and for the mix of 30% tyre oil was less while compared to that of diesel. For B30 mixes the thermal efficiency was higher compared with the results obtained with diesel as fuel. O2 and CO were lower for B30 mixes compared to that of diesel. [4] Showed that the butanol and pentanol are the two most important higher alcohols that come under the category of second/third-generation
biofuels which are capable of addressing major issues like environmental degradation and energy insecurity with the B20 blend being the most optimum. It was explained by Fayyazbakhsh A and Pirouzfar V that that the use of the tertiary additive in B20 blend can help to decrease the soot emission and to increase the cetane number. Using the metal additive to obtain the necessary temperatures for ignition is positive. Especially, using a nano metal additive with low heat conductivity lead to increase the power of the engine. The optimum conditions are obtained in the condition of 168 Nm and 1500 rpm. The new fuel blends developed in this study can be used for any kind of diesel engines. In their study in [6]Mathan Raj V, Subramanian LRG, Thiyagarajan S and Geo VE exhibited that (6) showed that the objective of the present study is to explore the effects of the minor addition of 1-pentanol and benzyl alcohol, classified respectively as aliphatic and aromatic type alcohols based on the classified hydroxyl based in their molecular structure. The experimental study reveals that the poor performance of B20 and B40 is enhanced with 1-pentanol (P) and benzyl alcohol (Bn) addition. Nox emissions are reduced with the addition of alcohol blends and 1-pentanol shows more promising results in terms of low NOx emissions compared to benzyl alcohol.

3. Project Implementation

3.1. Experimental Specification

| S.No | Parameters                      | Specifications                                      |
|------|---------------------------------|----------------------------------------------------|
| 1    | TYPE                            | 4 Stroke, Single Cylinder CRDI Vertical Water Cooled Engine |
| 2    | RATED POWER                     | 3.5 kW                                             |
| 3    | RATED SPEED                     | 1500 rpm                                           |
| 4    | BORE DIAMETER                   | 87.5 mm                                            |
| 5    | STROKE LENGTH                   | 110 mm                                             |
| 6    | COMPRESSION RATIO               | 17:5:1                                             |
| 7    | C.V. OF FUEL FOR DIESEL         | 42,500 kJ/kg                                       |
| 8    | C.V. OF SIMAROUBA BLENDED FUEL  | 40,352 kJ/kg                                       |
| 9    | DENSITY DIESEL                  | 840 kg/m³                                          |

Material Used:–
a) Diesel as the main fuel
b) Esterified Simarouba as additive.

c) 5% n-Pentanol as alcohol for Sample 1 at 500 bar.
d) 5% n-Pentanol as alcohol for Sample 2 at 600 bar.
e) 5% Ortho Benzyl Alcohol for Sample 3 at 500 bar.
f) 5% Ortho Benzyl Alcohol for Sample 4 at 600 bar.

3.2. Theoretical Analysis

All the experiments were conducted on a Kirloskar single-cylinder, naturally aspirated, water-cooled type, four-stroke, direct injection diesel engine at a constant speed of 1500 rpm and a rated power output of 5.2 kW. For the purpose of measuring and varying the loads, engine was coupled with an eddy-
current dynamometer with an electronic exciter. Fuel consumption is measured on a volumetric basis with the help of a burette and stopwatch. A K-type thermocouple connected to the digital display unit was used to measure the exhaust gas temperature. The gaseous emissions, namely HC, NOx, CO2, and CO emissions were measured using AVL Digas 444 model analyzer which works on the principle of non-dispersive infrared (NDIR). Smoke opacity was measured using AVL 437C model opacimeter working based on the light extinction method. A constant engine speed of 1500 rpm from lower to higher loads was used for the purpose of all the tests in the current study. No modifications were made on the engine and all the tests were conducted at steady-state conditions. Initially, the engine was run with diesel for 15 min to attain warm-up conditions. The emission parameters like HC, NOx were measured in terms of ppm, and CO were measured in terms of % volume which was converted to g/ kWh based on the number of moles.

3.3. Setup and Experimentation

Figure 1. Schematic View of Test Setup
Figure 2 shows the digital bomb calorimeter which was used for calculating calorific value of Simarouba oil. This was done to ensure that the use of Simarouba oil as an additive would not cause any harm to the CRDI engine.

Figure 3(a) shows the 4 Stroke single cylinder CRDI water-cooled vertical engine which was used in the test setup. Figure 3(b) shows the front view of the test setup for the performance of B20 blend.
Figure 4. AVL Smoke Analyzer

The AVL Smoke Analyser used for measuring the rates of emission of smoke, CO and CO₂, NOx, and HC particles is shown in Figure 4.

Four different blends of Diesel and Simarouba oil were used for the purpose of experiment. The blends are as follows:-

1. B20 Simarouba with 5% Benzyl Alcohol which was tested at 500 bar.
2. B20 Simarouba with 5% Pentanol which was to be tested at 600 bar.
3. B20 Simarouba with 5% Benzyl Alcohol which was to be tested at 500 bar.
4. B20 Simarouba with 5% Benzyl Alcohol which was to be tested at 600 bar.

All the blends were tested on the engine set-up at varying loads of 3, 6, 9, and 12 Kg, and the results were tabulated. A smoke analyser was used to for the purpose of emissions test. Emissions for the following gases were tested:

1. HC.
2. NOx.
3. Smoke.
4. CO and CO₂.

The emissions analysis and performance tests were carried out and represented graphically. The graphs plotted were as follows:

1. BP v/s BTE
2. BP v/s BSFC.
3. Load v/s CO.
4. Load v/s NOx.
5. Load v/s HC.
6. Load v/s Smoke.
7. Crank angle v/s Cyclic Pressure.
8. Crank angle v/s Heat Release Rate.

3.4. Graphical Analysis

It is understood from figure 5 that efficiency is found to be a considerable 9.08% and 5.5% more in 5% pentanol and 5% Benzyl Alcohol fuel blends respectively than that of diesel.
Figure 5. Brake Power v/s Brake Thermal Efficiency.

Figure 6. Brake Power v/s Brake Specific Fuel Consumption.

In figure 6 a graph is draw comparing Brake power and Brake Specific Fuel Consumption. It is shown that 5%P, 5% BA, diesel are consumed in an ascending order of magnitude. Similarly diesel at 600 bar was consumed more than diesel at 500 bar. Finally it can be observed that diesel at 500 bar had a noticeable 24.32% more consumption rate than both the fuel types. Every fuel type shoed better results under a pressure of 500 bar. The above mentioned values are that of 12 kg load condition.
Figure 7. Load v/s CO.

Figure 7 compares the CO emissions between various fuel types. In table 4.11 the engine is made to work under varied loads and different fuel mixtures are used to test the CO emissions. CO emissions were recorded to be increasing in the order 5%P blend, 5%BA blend, diesel. At 500 bars of pressure more CO was emitted by all the fuels used. CO emissions were significantly lesser when Simarouba blended fuel mixed with Benzyl Alcohol as an alcohol additive, followed by Pentanol as compared to diesel-run engines which had an accounting of 1.2 ppm at 500 bar and 1.02 ppm at 600 bar of pressure at 12kg load. The Benzyl alcohol blend only emitted .225ppm of CO at 600bar under 12kg load.

Figure 8. Load v/s HC.

It can be noticed that the HC emissions were lower at 500 bar pressure than 600 bar pressure for all the fuels. In figure 8 all the observations are made into a graph for better understanding. Figure 8 enumerates that HC emissions were lower at 27ppm with Pentanol at 600 bar as an additive as compared to both Benzyl Alcohol and Diesel. Benzyl Alcohol blend emitted about 46ppm at 600 bar pressure. The maximum emissions were accounted by diesel at both 500 bar and 600 bar with 63ppm and 72ppm respectively at 12kg.
Figure 9. Load v/s NOx.

Figure 9 shows the graphical comparison of NOx emissions with varied load conditions. It can be observed that under 600 bar pressure every fuel mixture emitted more NOx. NOx emissions were found to be higher in alcohol added fuels as compared to diesel. It is due to its higher release rate. Diesel was accounted to have the least amounts of emissions of NOx at both the varying pressures with 389 ppm and 399 ppm at 500 bar and 600 bar respectively. 5%BA at 600 bar showed maximum NOx emissions at 2192 ppm. The above mentioned values in the paragraph are taken at 12 kg load condition.

Figure 10. Load v/s Smoke.

It is evident from figure 10 that smoke emissions are lower in higher pressure condition (600 bar) when compared with lower pressure condition (500 bar) in same load conditions. The smoke emissions were maximum for 5%BA blend at 500 bar with 41.2%. It was least for B20 with 5% P blend at 600 bar with 20.1% smoke. The values mentioned in this paragraph are taken at 12 kg load condition.
Figure 11. Crank Angle v/s Cyclic Pressure.

Figure 11 explains that using Benzyl Alcohol gave better cyclic pressure when compared with Pentanol. However both Benzyl Alcohol and Pentanol showed better results than diesel.

Figure 12. Crank Angle v/s Heat Release Rate.

It is evident from figure 12 that Benzyl Alcohol has better heat release rate compared to Pentanol. Diesel showed the lowest heat release rate compared to both other fuels. Even though the heat release rate was slightly delayed, the peak release rate was improved with the addition of alcohol. Higher rate of evaporation and structure stability of Benzyl alcohol explains the above result.

4. Conclusion

In summary, this paper describes how the poor performance of B20 blend can be increased with the minor addition of alcohol. Experiments we conducted and the supporting literature is surveyed. The
literature clearly demonstrates that addition of alcohol can reduce the emissions and also increase the overall performance of the engine. After the conduction of experiments the following observations were made:

- Brake thermal (BT) efficiency is found to be a considerable 9.08% and 5.5% more in 5% pentanol and 5% Benzyl Alcohol fuel blends respectively than that of diesel.
- While comparing brake specific fuel consumption (BSFC) it was found that diesel has a noticeable 24.32% more consumption rate than both the fuel types.
- The emission rate of CO was found to be 81.25% and 81.33% less with 5% pentanol and 5% Benzyl Alcohol fuel blends than that of diesel.
- Diesel released .5714 and .2698 times more Hydrocarbon (HC) compared to 5% pentanol and 5% Benzyl Alcohol respectively.
- NOx emissions are higher in both 5% pentanol and 5% Benzyl Alcohol by 445.5% and 463.47% respectively due to higher release rate.
- Smoke emissions are lower in higher pressure condition (600 bar) when compared with lower pressure condition (500bar) in same load conditions.
- Benzyl Alcohol gave better cyclic pressure when compared with Pentanol. However both Benzyl Alcohol and Pentanol showed better results than diesel.
- Benzyl Alcohol has better heat release rate compared to Pentanol. Diesel showed the lowest heat release rate compared to both Benzyl Alcohol and Pentanol.

From all the observations mentioned above it is evident that Benzyl alcohol gives better results as compared to pentanol. Alcohol giving better results as compared to pentanol. Therefore in conclusion, the addition of vegetable oils is a simple and cost-effective method to improve performance without compromising on emissions rates. In fact the emissions were lower. B20 blend proved to be an optimum blend with an addition of 5% Benzyl alcohol as a better additive rather than Pentanol as it showed better results with both performances as well as emissions plus it had a better peak heat release rate.

References

[1]. Sharma P, Dhar A. Effect of hydrogen fumigation on combustion stability and unregulated emissions in a diesel-fuelled compression ignition engine. Applied Energy. 2019; 253.
[2]. Saravanan CG, Kiran KR, Vikneswaran M, Rajakrishnamoorthy P. Impact of fuel injection pressure on the engine characteristics of CRDI engine powered by pine oil biodiesel blend. Fuel. 2020; 264.
[3]. Shahir VK, Jawahar CP, Vinod V, Suresh PR. Experimental investigations on the performance and emission characteristics of a common rail direct injection engine using tyre pyrolytic biofuel. Journal of King Saud University - Engineering Sciences. 2020; 32(1): p. 78-84.
[4]. M VB, K MM, G APR. Butanol and pentanol: The promising biofuels for CI engines – A review. Renewable and Sustainable Energy Reviews. 2017; 78: p. 1068-1088.
[5]. Fayyazbakhsh A, Pirouzfâr V. Investigating the influence of additives-fuel on diesel engine performance and emissions: Analytical modeling and experimental validation. Fuel. 2016; 171: p. 167-177.
[6]. Mathan Raj V, Subramanian LRG, Thiyagarajan S, Geo VE. Effects of minor addition of aliphatic (1-pentanol) and aromatic (benzyl alcohol) alcohols in Simarouba Glauc-diesel blend fuelled CI engine. Fuel. 2018; 234: p. 934-943.