Improvement in the performance of Simarouba blended diesel fuel using Di-Ethyl Ether and Di-Methyl Carbonate as additives in a CRDI engine

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Abstract. This study investigates the effects of B20 and additives added to the B20 blend when run in a CRDI engine under different loading conditions. Experimental studies compared to diesel show the poor performance of B20. The addition of DMC (dimethyl carbonate) and DEE (diethyl ether) in B20 significantly improved. Under high load conditions, the performance characteristics of BTHE of B20 DMC are relatively higher and lower BSFC than B20 DEE values. It can be seen from the emission results that NOx emissions are higher due to proper combustion in the case of B20 DMC. The emission characteristics show that B20 with 5% DMC showed better results than other samples present. This happens because of better and proper combustion of the fuel. It showed better results in the emission of CO and hydrocarbons while the DEE sample at 600bar showed better results for smoke emission. The combustion characteristics also show the same result that B20 with 5% DMC is a better fuel when compared with the rest of the samples. Though in performance characteristics we noted that B20 with 5% DEE showed better results in the graph between crank angle vs cylinder pressure and crank angle vs heat released.

Keywords: Fuel, Engines, Performance, Emission, Combustion, Bio-diesel.

1. Introduction

With our fossil reserves depleting at a rate faster than expected and the deteriorating air quality, a need for an alternative to conventional energy sources has never been as prominent. One such alternative showing great promise is biodiesels. Biodiesels are produced by a process known as transesterification. In the transesterification process, vegetable and waste cooking oils, animal fats containing alcohol in front of a catalyst leading to the formation of ester and glycerol. Glycerol is then further processed and removed after which biodiesel is obtained. It is observed that without modification to the engine, biodiesels can be used as an alternate source of fuel. Biodiesel does not contain Sulphur atoms in it, which leads to an almost
complete reduction in Sulphur oxide emissions when used. The oxygen content present in biodiesels improves the combustion process and decreases oxidation potential. Biodiesels have higher viscosity compared to conventional diesel, which leads to a problem during fuel injection. Biofuels have poor atomization of fuel because of their high viscosity that leads to slower combustion or sudden rise in pressure within the cylinder. Biofuels have high oxygen content and viscosity, which leads to a longer combustion duration that is favorable for the formation of more NOx emissions. Various methods were proposed for advancement in the performance of CI engines using direct vegetable oil. One such method is to use alcohol with diesel and vegetable oil blends. [13] addition of orange oil, diethyl ether to clean cottonseed oil showed a 15.35% increase in brake thermal efficiency compared to diesel. A study by Devan P K  [11] shows that methyl esters of paradise oil and eucalyptus oil used in different combinations when used in a CI engine show diminished HC and CO emissions levels while a raise in NOx emissions and brake thermal efficiency at full load condition. Diesel engine run on paradise oil and methyl ester alloys shows abbreviated emissions of smoke and hydrocarbon respectively. It was also observed that methyl esters alloys of paradise oil have slightly lower brake thermal performance compared to diesel. [10] alcohol use for an internal combustion engine is a viable option as alcohol can be produced by biorefineries, thereby reducing the use of fossil resources. [2]. Simarouba oil is obtained from the Simarouba glauca plant, which grows in a wide temperature and altitude range. Simarouba oil has a higher viscosity than diesel which leads to problems when operating in a CI engine. It also has a higher calorific value and can be used as a blend in low cetane fuels such as alcohol and diesel. [8]

2. Methodology

The blends of Simarouba oil and diesel have been formed by a mixture of dimethyl ether and diethyl carbonate. For the 1st blend, 20% vol of Simarouba oil mixture is mixed with 5% DMC and for 2nd blend 20% Simarouba oil mixture is used with 5%DEE

Table 1: Specification of blends

| Fuel blends  | Composition                     |
|--------------|---------------------------------|
| B205%DMC    | 20% of Simarouba oil and diesel mixture + 5% DMC |
| B205%DEE    | 20% of Simarouba oil and diesel mixture + 5% DMC |

Table 2: Fuel properties of B20 mixed with diethyl ether and dimethyl carbonate

| Fuel Blends | Flash Point | Fire Point | Viscosity |
|-------------|-------------|------------|-----------|
| Diesel      | 54          | 64         | 3.6       |
| B20         | 105         | 109        | 9.9       |
| B20(5%DEE)  | 31          | 36         | 7.2       |
| B20(5%DMC)  | 41          | 45         | 7         |

The setup for testing consists of a single-cylinder, CRDI VCR engine of 4 strokes that is connected to a dynamometer. It consists of instruments that are used for combustion, such as pressure and temperature at
which combustion will occur, crank angle, load measurements, and air-fuel flow. The signals received are linked to the computer by using a high-speed data device. The setup includes a panel box that consists of the airbox with a manometer, twin fuel tank and fuel-measuring unit for measuring heights, transmitters for air-flow measurement, an indicator, and a piezo-powering unit. They are supplied with a rotameter for cooling of engine and water flow measurement. A program has been uploaded in CRDI engine for the opening of ECU for Diesel injection and fuel injector, rail pressure sensor for rail movement and pressure regulating valve, for the positions of the crank, a crank position sensor is used. The software that is used for the project is Engine Soft is by Apex Innovations Pvt. Ltd. It is accustomed to verify the performance of the engine by watching the entire system. This software is used to calculate the inlet pressure exhaust pipes pressure and cylinder pressure. It analyzes the horsepower of the engine, torque, and volumetric efficiency of the engine.

Figure 1: Engine testing set up
Blends of B20 with DEE and DMC and diesel are used to initiate the engine. Multiple loading conditions were measured with the help of a coupling system with an eddy current dynamometer. The setup comprises a panel box which consists of a twin fuel tank, on-air box, fuel measuring unit, manometer, transmitters for the flow measurements of air and fuel, an indicator to have a check on the process, and a piezoelectric powering unit. The running speed for the engine set at 1500 rpm and other engine specifications are given below.

| FEATURES         | EXPOSITION                  |
|------------------|-----------------------------|
| Model            | Computerized CRDI-VCR engine|
| Make             | Kirloskar                   |
| Engine           | Four strokes, single-cylinder|
| Compression ratio| 12-18                       |
| stroke           | 110 mm                      |
| Bore diameter    | 87.5 mm                     |
| capacity         | 661 cc                      |
| Power            | 3.5 kilowatt at 1500 rpm    |
| Dynamometer      | Eddy current                |

3. Results and Discussion

3.1 Performance characteristics

3.1.1 Brake Thermal Efficiency (BTHE)

The efficiency of the engine to transfer energy produced by the combustion of fuel into mechanical work is known as brake thermal efficiency. The brake thermal efficiency of two blends are shown in figure 2, for two different pressures at 500 and 600 bar. On increasing brake power and pressure, the BTE of all fuel blends shows an increasing trend. The maximum efficiency was observed for B20 blended fuel with 5%DEE at 600 bars. Blended fuels with additives of Diethyl ether and Dimethyl carbonate show a higher BTE in diesel and B20, this could be due to the low calorific value that the blended fuel possesses.

3.1.2 Brake Specific Fuel Consumption (BSFC)

The amount of fuel consumed per hour to generate unit brake power is known as brake-specific fuel consumption (BSFC). In figure 3, we see a decrease in the values of brake-specific fuel consumption when the load is increased. The BSFC is lower for the two blends with additives of dimethyl ether and dimethyl carbonate (B20 5%DEE & B20 5%DMC) than that of diesel. This phenomenon is shown due to the higher brake thermal efficiency of blended fuels compared to B20 and diesel, which results in lower brake specific fuel consumption.
Figure 2: Load (Kg) vs Brake Thermal Efficiency (%)

Figure 3: Load (kg) vs Brake Specific Fuel Consumption (g/(KW-hr))
3.2. Emission characteristics

3.2.1. CO Emission

Carbon monoxide is produced when there is a scarce amount of oxygen present for the combustion process. In figure 4, we see that the mean values of carbon monoxide emissions for all fuels decrease to 50% load from no-load conditions, this is due to traces of partial combustion is higher in higher loads or due to less reaction time. As the load is increased, a richer fuel mixture is burned which leads to lesser oxygen being present for combustion and higher CO emission. This is due to traces of partial combustion is higher in higher loads or due to less reaction time. The CO emissions for diesel were observed to be maximum, followed by B20. By the presence of higher oxygen in blends, lower CO emissions are observed.

![Figure 4: Load (kg) vs CO Emission (%vol)](image)

3.2.2. HC emission

Hydrocarbon emissions just like CO emissions result from incomplete or partial combustion, caused as a result of non-optimal temperature in the adjacency of the cylinder wall. Thus, by increasing the load the hydrocarbons emission rises. From figure 5, we see that HC emissions increase to 75% load, and then there is a sharper increase in HC emission till full load condition. The diesel and B20 Blend showed maximum emission while the minimum HC emission was observed for B20 5%DMC at 600 followed by B20 5%DEE at the same pressure, Hence, it is concluded as the HC emissions decrease with an increase in pressure and higher oxygen content in the fuel.
3.2.3. NO\textsubscript{x} Emission

From figure 6, we observe that NO\textsubscript{x} emission rises until 75\% load, after which a decrease in NO\textsubscript{x} emission is observed till full load condition. NO\textsubscript{x} emissions characteristics are important to study alternative fuels. NO\textsubscript{x} emissions are influenced by the oxygen content, in-cylinder temperature, and reaction time. From figure 8 we see that the heat released by the blends is higher than that of diesel, which leads to higher exhaust gas temperature of the blends when compared to diesel, which in turn increases the NO\textsubscript{x} emissions. The highest NO\textsubscript{x} emission at full load condition by B20 DEE at 600 bar pressure. It was also observed that all fuel blends at full load conditions have higher NO\textsubscript{x} emissions than diesel.

3.2.4. Smoke

Smoke occurs when there is incomplete combustion, from figure 7, one can infer that smoke opacity for all fuels was increasing with an increase in load and decrease in the inlet pressure. This is due to traces of partial combustion is higher in higher loads or due to less reaction time. Minimum opacity was noted for B20 blended fuel with 5\% Diethyl ether at 600 bar pressure, followed by 5\% Dimethyl carbonate at 600 bar pressure and maximum opacity was observed for B20, due to its high viscosity. Blended fuels with additives of Diethyl ether and Dimethyl carbonate were found with lower soot content and other gas particulates due to the higher content of oxygen during combustion tending to adequate combustion.
Figure 6: Load (kg) vs NOx emission (ppm)

Figure 7: Load (kg) vs opacity (ppm)
3.3 Combustion Characteristics

3.3.1. Heat Release Rate (HRR)

The Heat release rate as shown in figure 8, is maximum for blend B20 5% Dimethyl carbonate i.e., 55KJ followed by B20 5% Dimethyl carbonate 50KJ at 600 bars around the crank angle of 348°. The maximum heat release rate of diesel was found to be 39KJ at a 357° crank angle. This huge difference between the values of diesel and the blends was due to the elevated oxygen content existing in blends thus leading to better fuel combustion.

![Figure 8: Crank angle (degree) v/s Heat release (KJ)](image)

3.4. Pressure v/s Crank angle characteristics

Figure 9, shows the variation for pressure in the cylinder at full load conditions under (-50° to +50°). The crowning pressure was highest for the blends, at 5° reaching a value of 79.5 bar. The diesel showed much lower values at around 10° which indicates the value of 61.4 bar. The low fire point leads to a more intense pre-combustion phase for blends than Diesel.
4. Conclusion

We have studied the performance, combustion, and emission characteristics for two different fuel blends i.e., B20 with 5% DEE and B20 with 5% DMC at 500 bar and 600 bar each. Our study has focused on finding a blend with the most optimized results so that it could reduce and replace fossil fuel (diesel) in the future. We have arrived at the following conclusion after performing the experiments.

The emission characteristics show that B20 with 5% DMC showed better results than other samples present. This happens because of better and proper combustion of the fuel. It showed better results in the emission of CO and hydrocarbons while the DEE sample at 600 bar showed better results for smoke emission.

The combustion characteristics also show the same result that B20 with 5% DMC is a better fuel when compared with the rest of the samples. Though in performance characteristics we noted that B20 with 5% DEE showed better results in the graph between crank angle vs cylinder pressure and crank angle vs heat released.

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