Experimental investigation of performance and emissions of CRDI engine fuelled with kapok ester oil blended with diesel

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Abstract. As world oil reserves is going down rapidly and the world energy demand is going up, along with the increasing Greenhouse emission, we need to support the initiative by minimizing the emission and maximising the efficiency. We need to grow awareness among people of the importance of Biofuels which will be one of the energy source in the near future. This paper deals with fuel of kapok-ester oil and Diesel oil blend in the Proportional of (10% of kapok-ester oil and 90% of diesel oil) and B20 (20% of Kapok-ester oil and 80% of Diesel oil). The properties of the blended fuel were measured according to the ASTM standards. The Experiment setup includes of single cylinder four stroke CRDI diesel engine with varying load at constant speed. The experiment results show that increasing the Kapok-ester oil proportion increases the brake thermal efficiency, decrease CO and increase the NOx emission.

1. Introduction
With a rapid economic growth of development and population, there is a high demand of energy. As the fossil fuels are in limited quantity, there is a need for an alternative fuel [1]. Researchers are focussing on biofuels because it is a renewable source and there is less emission of harmful gases which will pollute the environment. There are many combinations that can be made to increase the performance of the machinery. These researches have proved that there may be a chance of producing alternative fuels which may replace fossil fuels with better performance and lower emission in the upcoming future. Many researches that have been conducted use a blend of vegetable oils or mix it with diesel to bring their performance close or more than that of a fossil fuel. Experiments with various biodiesel-ethanol and biodiesel-methanol, cashew nutshell oil-camphor oil, biodiesel-eucalyptus oil are in progress. It was observed that cetane number has a major effect and plays a major role on combustion and emission characteristics. Exhaust emissions are affected indirectly by Cetane number by increasing or decreasing the ignition period. Fuels with more cetane number perform better on a diesel engine as they increase the quality of combustion and decrease the delay in ignition. Whereas fuels with lower cetane number decrease in ignition time and the combustion does not occur properly. In this paper, we are investigating on the performance and emission characteristics of Kapok ester and diesel in CRDI engine. Different blends were prepared of Kapok ester and diesel as B20 (20% kapok ester, 80% diesel) and B10 (10% Kapok ester, 90% diesel) at 400 bar pressure. With these parameters, performance and emission characteristics were calculated in a CRDI engine.[2,3] The intentions of this project is to find out the best fuel blend ratio of Kapok ester and Diesel at a specific pressure based on its characteristics like performance, emission and combustion.[4,5].
2. Biodiesel and fuel preparation

2.1. Kapok ester
Kapok ester is prepared from raw Kapok oil, extracted from Kapok tree [6,7,8]. Trans-esterification is performed over raw Kapok oil to form kapok ester. T.Senthil Kumar et al [2,3,4] stated that his process is done to convert fatty acids to form esters and glycerol in the presence of catalyst. There are other methods for instance glycerolizes, acid catalysis and alkali catalysis are used to obtain satisfactory yields of biodiesel. Trans-esterification is performed in two steps to decrease the viscosity of the free fatty acid and increase the biodiesel production. Initially acid catalysed esterification is performed to covert free fatty acid to ester, following this process base catalytic trans-esterification is performed to convert triglycerides into esters [9]. Saponification reaction of fatty acid is mentioned in equation 1 and 2 and Transesterification of triglycerides with alcohol is mention in equation 3.

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\begin{align*}
\text{RCOOR} + \text{H}_2\text{O} & \rightarrow \text{RCOOH} + \text{ROH} \quad (1) \\
\text{RCOOH} + \text{ROH} & \rightarrow \text{RCOOR} + \text{H}_2\text{O} \quad (2)
\end{align*}
\]

\[
\begin{align*}
\text{CH}_3\text{OOCR}_1 + \text{CH}_2\text{OH} & \rightarrow \text{R}_1\text{COOR} + \text{CH}_3\text{OH} \\
\text{CHOOCR}_2 + 3\text{ROH} & \rightarrow \text{R}_2\text{COOR} + 3\text{CHOH} \\
\text{CH}_3\text{OOCR}_3 & \rightarrow \text{R}_3\text{COOR} + \text{CH}_2\text{OH} \quad (3)
\end{align*}
\]

2.2. Diesel
It is a liquid fuel which is used in a diesel engine. It is ignited with no spark but by the compression of the inlet air mixture and then the fuel is injected through the valves. High thermodynamic efficiency and efficiency of the fuel gives it a upper hand over other fuels, which can be used in diesel engine. The composition of diesel includes 75% of saturated hydrocarbon and 25% of aromatic hydrocarbon. There are many emissions of gases when diesel is ignited, such as hydrocarbon (HC), carbon monoxide (CO), Nitrogen oxide (NOx), Carbon dioxide (CO2) and Oxygen (O2).

2.3. Preparation of blends
The blends will be a mixture of diesel and kapok ester in two concentrations which are, B10 and B20. B10 composition is 10% by volume of kapok ester and 90% by volume of diesel as a mixture.B20 composition is 20% by volume of kapok ester and 80% by volume of diesel as a mixture. The total volume of blend to be used was decided to be 4000ml or 4L. Therefore, in the case of B20 blend, 800ml or 0.8L of kapok ester was used to constitute the 20% of the mixture and 3200ml of diesel was used to constitute the 80% of the mixture. Both composites of the mixture were mixed together with the help of a magnetic stirrer. Magnetic stirrer uses the principle of rotating magnetic field as a medium, to mix the solutions. The rotating magnetic field created by the machine rotates the stir bar which is already dipped in the solution. An rpm of 1580 is given for the duration of 15 minutes for the mixing of the two blend components. The same procedure is followed for the B10 blend but instead of 800ml of kapok ester, 400ml is used along with 3600ml of diesel to constitute 4000ml of blend.

2.4. Fuel Properties
All the fuel physical and the chemical properties of the raw Kapok, Kapok –ester, Diesel and the fuel blends B10 and B20 has been measured and listed in the table 1.
3. Experimental setup

3.1. Testing setup

CRDI engines are used commercially in engine and Industrial purposes to increase the efficiency of the fuel [11] [12]. The testing setup includes a single cylinder four stroke CDRI diesel engine with VCR linked with eddy current dynamometer. The setup includes sensors to measure combustion pressure, crank angle, airflow, fuel flow, temperatures and load. These signals are interfaced to computer through high speed data acquisition device. The measurement of fuel flow consumption was done using a burette and a stopwatch [12]. The load range used while running the engine were 0kg, 3kg, 6kg, and 12kg during experiment. In the case of the research performed by Mandeep Singh et al [10] three test conditions were used i.e. low load, part load and high load. Schematic diagram is showing in figure 1. Specification of engine is given in table 2.

Table 1. Properties of the fuels and fuel blends.

| Fuel        | Raw Kapok | Kapok Ester | Diesel | B10 | B20 |
|-------------|-----------|-------------|--------|-----|-----|
| Formula     | -         | -           | C10H20 | 855.5 | 856 |
| Density (Kg/ml) | 900       | 860         | 855 | 4.5 | 4.75 | 5 |
| Kinematic viscosity (cst) | 12     | 7           | 4.5 | 4.75 | 5 |
| Calorific value (KJ/Kg) | 40590    | 43166.21    | 44000 | 43916 | 43833 |
| Cetane no.  | 37        | 51          | 52 | 51.9 | 51.8 |

Figure 1. Schematic representation of CRDI engine.

Table 2. Specification of engine.

| Feature       | Description                                                      |
|---------------|------------------------------------------------------------------|
| Model         | CRDI - VCR Engine test (Computerized) - 244                      |
| Engine        | Make Kirloskar, Single cylinder, 4 stroke, water cooled, stroke 110 mm, bore 87.5 mm, 661 cc. |
| Dynamometer   | Type eddy current, water cooled with loading unit                |
| Capacity      | Power 3.5 KW, 1500 rpm, length of stroke 110 mm                  |
| Temp. sensor  | Type RTD, PT 100 and Thermocouple, Type K                       |
| Load sensor   | Load cell, type strain gauge, range                              |
3.2. Engine Software
The software used is Engine Soft is Lab view. Which can be used to determine engine performance on monitoring system. The software helps in evaluating power, efficiencies, fuel consumption and heat release. The software stores the information regarding combustion and performance characteristics and the related digital graphs can be plotted on the software. Different graphs can be obtained while running the engine. Important signals are measured, contained and presented in graph, while the engine is in RUN mode.

3.3. Exhaust Gas Analyser
The exhaust gas analyser helps in measuring NOx, CO2, HC, and CO emissions present in the exhaust gas. The principles on which CO sensors (and other types of gas) is bases on, are infrared gas sensors (NDIR) and chemical gas sensors. MOT test is done by CO sensor to measure the carbon monoxide content in exhaust gas. The specs for the different Exhaust gas determined and can be seen in table 3 below.

Table 3. Specification of Exhaust gas analyser.

| GAS               | Range of measurement |
|-------------------|----------------------|
| CO                | 0 - 10% of volume    |
| Hydrocarbon       | 0 - 20000 (ppm)      |
| Carbon dioxide    | 0 - 20% of volume    |
| Nitrogen oxide (NOx) | 0 - 5000 (ppm)       |

4. Performance characteristics

4.1. Brake Thermal Efficiency (BTHE)
BTHE represents the brake power of an engine as a function of the thermal input from the fuel. It is a ratio of brake power to heat supplied to the engine (BP/mf x C.V.), where C.V. denotes calorific value of the fuel (kg/s) and mf denotes mass of the fuel (kg/s). The capacity of an engine to convert the heat energy acquired from the fuel into mechanical energy is measured with the help of BTHE.

The brake thermal efficiency of two blends B10 and B20 of kapok ester and diesel along with diesel at 400 bar pressure is shown in the graph below. It is observed that the BTHE of the B20 blend as well as B10 blend is slightly higher than that of diesel. Just like D.Ramesh et al [1] noticed in his research with jetropha oil. Maximum BTHE for B10, B20 and diesel at maximum load are at 400 bar conditions were, 18.62%, 20.5% and 20.1% respectively. The increase in the BTHE for the B20 and B10 blends maybe due to higher oxygen content which in turn is the source for higher combustion rate of the fuel at high temperature. The rate of BTHE has increased upto 3/4th of the full engine load, and decreases after further increase in load.[2,10,14]
Figure 2. Brake thermal efficiency with respect to engine brake power at 400 bar injection pressure for the B10, B20 blends of kapok ester and diesel.

4.2. Brake Specific Fuel Consumption (BSFC)
BSFC is a quantity that measures the efficiency of prime movers of a combustion engine which burns fuel and generates rotational power at the shaft or the crankshaft. In Figure 3, one can see the decreasing trend in the values of BSFC with respect to increase in load or increasing brake power [10]. BSFC is the input energy to useful work ratio and it thus decreases with increase in load or brake power. It is evident that the specific fuel consumption at full load is slightly lower for diesel than the B10 and the B20 blends of kapok ester. Whereas, D Ramesh et al [1] noticed that fuel consumption range increased and was found similar under all loads.

Figure 3. Specific fuel consumption with respect to engine brake Power at 400 bar injection pressure for B10, B20 blends of kapok ester and diesel.

5. Emission characteristics
5.1. CO emission
Carbon monoxide is the product of incomplete or partial combustion of the fuel which is the effect of the lower amount of oxygen being released in the engine for the combustion of fuel [10]. After the completion of the fuel combustion, carbon content present in the fuel is converted into carbon dioxide but in partial combustion due to low availability of oxygen the intermediate gas produced is carbon monoxide. In the figure 4 we can see the increasing trend in CO emissions with increasing load or brake power. Increasing partial combustion or less reaction time at higher loads might be the reason
for increasing CO emissions [14]. B10 and B20 blends have a slightly higher CO emissions as compared to diesel.

![Figure 4](image4.png)

**Figure 4.** Carbon monoxide emissions with respect to engine brake power at 400 bar injection pressure for B10, B20 blends of kapok ester and diesel.

### 5.2. CO₂ emissions

CO₂ emissions follow the same characteristics as that of the NOx emissions. Carbon dioxide is the by-product of complete combustion of fuels in the presence of a good supply of oxygen. The B10 and the B20 blends have a slightly higher carbon dioxide emission with respect to that of diesel, implying that the B10 and the B20 blend have a better combustion than the diesel fuel.

![Figure 5](image5.png)

**Figure 5.** Carbon dioxide emission with respect to engine brake power at 400 bar injection pressure for B10, B20 blends of kapok ester and diesel.

### 5.3. HC emissions

Hydrocarbon emissions is basically the unburnt fuel which is caused due to non-optimal temperature near the cylinder wall. Due to Incomplete combustion is also a cause for hydrocarbon emission [10]. Hence, HC will show the same characteristics as that of CO emissions i.e., it increases with increase in load. Both the blends along with diesel show the same characteristics as mentioned above. The percentage volume emissions of HC for both the blends was analysed to be slightly more than diesel.
Figure 6. Hydrocarbon emission with respect to engine brake power at 400 bar injection pressure for B10, B20 blends of kapok ester and diesel.

5.4. NOx emissions
From the figure 7 one can observe that NOx emission increases up to 75% of the load and then it starts to decrease after the afore mentioned load percentage. According to many studies, that blending the diesel with biofuel increases the NOx emission [10]. This trend can be seen in both B10 and B20 blends along with diesel. The emission characteristic of NOx is the exact reverse as that of CO and HC emissions i.e. it decreases after reaching the 75% of load while CO and HC increases after hitting the same mark. While studying the alternative fuel the study of NOx emissions characteristics are important. The NOx emission calculations is based upon the in-cylinder temperature, oxygen content and time taken for the reactions to occur [12]. In the given BP v/s NOx graph, the emission characteristics of NOx in the blends are higher than the conventional diesel fuel.

Figure 7. Nitrogen oxides emission with respect to engine brake power at 400 bar injection pressure for B10, B20 blends of kapok ester and diesel.

6. Combustion characteristics

6.1. Heat Release Rate
As it can be seen in figure 8 the changes in Heat release rate (HRR) of diesel fuel and the fuel blends B10 and B20 w.r.t changing crank angle at 12KG which is full load condition. The heat release rate of both blends shows similar trends. As determined from the graph the HRR for the diesel is slightly elevated as compared to the other blends, implying better atomization of the fuel leading to better
combustion thus higher HRR. The maximum HRR of diesel was 40.3KJ was found at 350° crank angle. While the highest value of heat release rate for fuel blends B10 and B20 were 32.91KJ and 33.06KJ found at 359° and 358° crank angle respectively. By following the trends, it can implied that there is an ignition delay in case of fuel blends compared to diesel fuel. It can be observed that among the fuel blends B20 has a higher HRR than B10, i.e. there was a better combustion process in case of B20 fuel blend. Similar to this S.Vetharaj [5] et al stated that there will be a drop in the rate of peak heat release of the blends than diesel taking higher viscosity and spray characteristics into account.

Figure 8. Heat release rate with respect to crank angle at 400 bar injection pressure for B10, B20 blends of kapok ester and diesel.

6.2. Pressure v/s Crank angle characteristics

The pressure vs crank angle figure 9 was plotted for the blends B20, B10 as well as diesel at 400 bar injection pressure at maximum load of 12Kg. After analysing the graph we can observe that the cylinder pressure for diesel displayed the maximum value of 59.94 bar then followed by B10 blend and B20 blend with 56.77bar and 55.06bar as their respective cylinder pressure.

Figure 9. Pressure with respect to crank angle at 400 bar injection pressure for B10, B20 blends of kapok ester and diesel.

6.3. Cumulative HRR v/s crank angle characteristic

The cumulative heat release rate for the blends B10, B20 and diesel were correlated with each other and with respect to the crank angle of the crankshaft. The following graph shows us that both the blends B10 and B20 along with diesel show almost the same cumulative HRR properties between the crank angle ranges of 330 to 410 degrees. According to the graph, CHRR decreases at first then increases with increase in crank angle.
7. Best Fuel Blend

By analysing the emission and performance characteristics of the fuel blends B10 and B20, the results shown by B20 were relatively more satisfying and efficient than B10. At maximum load conditions the performance characteristics like BTHE of B20 is relatively higher and lower BSFC than B10 values. By determining the emission results it was observed that the NOx and CO2 emissions are higher due to proper combustion, in case of B20.

8. Conclusion

The "Performance, Combustion, and Emission characteristics" have been studied for the fuel blends B10 and B20 along with Diesel. This study of the fuel blends has a focus on finding a better fuel blend which could find a better utilization and replace fossil fuel Diesel in near future. By analysing the results following conclusions have been made.

The performance characteristics of the fuel depends upon the combustion process in cylinder, that is better atomization of fuel leads to better combustion thus better BTE. Despite of ignition delay more than diesel as shown in the graph, B20 proved to be have better BTE, with low volatility trend in graph.

Though in emission values of CO and HC of B20 were elevated than diesel and B10, the larger values of NOx and CO2 emissions signifies the better atomization leading to proper combustion of the fuel in the cylinder.

In Combustion characteristics of the diesel HRR have shown a significant larger value than the other fuel blends with respect to crank angle. This difference in HRR value was due to the higher ignition delay in case of B10 and B20 fuel blends. But since B20 is having HRR value slightly greater than B10. Thus concluding the B20 to be better fuel blend option than B10.

It was observed from the Pressure v/s Crank angle characteristics graph that in case of diesel the cylinder pressure witnessed a greater increase as compared to B10 and B20. B10 has a slightly larger Cylinder pressure than B2.

9. References

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