Investigation of performance and emission characteristics of four stroke single cylinder diesel engine with cotton-seed biodiesel

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Abstract. In present article, engine performance and emission characteristics were investigated with various blends of cotton-seed bio diesel and diesel. Reason to choose cotton seed bio diesel is its thermophysical properties which is identical with diesel. It also consists of higher oxygen content which directly improves combustion efficiency of the engine. Four Stroke, Single cylinder, diesel engine was tested under various blends consist of 5%, 10%, 15% and 20% (by Vol) of cotton seed biodiesel. Experimental results found no significant variation in brake thermal efficiency up to 10% biodiesel blend then it found to be dropped gradually. Brake thermal efficiency decreased by 12% at 20% biodiesel blend. CO & HC emissions exhibited decreasing trends with percentage increase in biodiesel concentration. Increase in NOx emission was insignificant up to 10% biodiesel blend. It can be further noted that 10% biodiesel diesel blend shows optimized performance and emission results.

Keywords. Cotton seed oil, Biodiesel, CO & HC emission, NOx emission

1. Introduction
Several serious issues faced by world is depletion of fossil fuels, environmental pollutions and global warming. On other side, demand of fossil fuel is increasing rapidly due to its excessive use in automobiles, industries, agriculture field, power industries. Use of alternate fuels is one of the effective ways to solve said problems. Various vegetable oils available in nature consist great potential as alternate fuels but its direct use in diesel engine may cause several issues like carbon deposition in cylinder walls, cylinder heat, injector and combustion chamber, high wear & tear of moving parts and poor atomisation due to high viscosity of oils. It is advisable to use transesterification process to reduce viscosity of vegetable oils. Esterified vegetable oils are generally termed as bio-fuels. Various biofuels are derived from various raw oils like rapeseed, sunflower, coconut, peanut, jatropha, mahua, karanja and cotton seed [1-4].

Biodiesel can be considered as fatty acid methyl or ethyl ester developed from unused or used vegetable oils and fats of animals. Biodiesel is reported a clean fuel by many researchers due to absence of sulphur,
absence of aroma and consists of approximately 10% oxygen which improves combustion. It poses high cetane number (50-52) which enhances the ignition quality even when it is blended with diesel. A wide range of opportunities could be seen with the extracted biodiesel from plant derived oils as large landslide is available with sufficient solar energy around the year [5-7].

According to Subramanian et al. [8], more than 270 specimens of trees can produce seeds having oil content. Hence, there is a considerable potential for non-edible oil source from various plants for production of biodiesel which is a good alternate of conventional diesel fuel. Azam et al. [9] reported that various oil-bearing plants in India remains unutilized and have great potential to be used as raw materials for production of biodiesel.

Yesilyurt & Aydin [10] have investigated performance and emission characteristics of four stroke, single cylinder diesel engine using tertiary blend of Cotton seed biodiesel, diesel and DEE (oxygenated fuel additive) and reported around 18% drop of thermal efficiency and 30% rise of specific fuel consumption for 10% DEE blended in binary blend of D80B20. CO emission decreased by 40% and decrease in HC emission was around 35%. Nabi et al. [11] have performed an experiment on single cylinder four stroke diesel engine with cotton seed oil and diesel blend fuel. Results showed that efficiency and fuel consumption remain almost unchanged for 10% biodiesel blended in diesel with considerable improvement in CO and HC emissions. Aydin & Bayindir [12] have tested cotton seed biodiesel in diesel engine and concluded that the variation in thermal efficiency is insignificant up to 15% biodiesel blend while there is a considerable improvement in emission characteristics of diesel engine. Karabektas et al. [13] have investigated effect of preheated cotton seed oil on performance and emission characteristics of diesel engine and found that preheating of cotton seed oil at 90°C shows optimum performance and emission characteristics. It was also concluded that NOx emission rises with increment of preheating temperature of oil. Cotton seed oil methyl ester and diesel blend was used in four stroke single cylinder air cooled diesel engine by Ilkilic & Yücesu [14]. They reported that performance of the engine remains unchanged for lower blend percentage while considerable reduction in CO and NOx emission.

2. Preparation of bio-diesel

India is the second largest country in cotton seeds productions worldwide. Cotton seed possess considerable quantity of oil content. Transesterification process was used to convert cotton seed vegetable oil in to biodiesel. In the single step transesterification process, NaOH was used as an alkali catalyst and reacts with vegetable oil to separate fatty acid content from it. Then mixture was allowed to get reacted with methanol for 60 minutes. During this process, temperature of the chemical was maintained at 55°C. Properties of rape seed oil and its biodiesel is compared in Table 1.

| Property             | Diesel  | Cotton seed biodiesel |
|----------------------|---------|-----------------------|
| Chemical Formula     | C_{14}H_{25} | C_{17}H_{32}O_{2}     |
| Density (kg/m^3)     | 815     | 885                   |
| Kinematic Viscosity (mm²/sec) | 2.5 | 4.8                   |
| Calorific Value (MJ/kg) | 42   | 39                    |
| pH                   | 7       | 6.5                   |
| Flash Point (°C)     | 60      | 170                   |
| Oxygen Content (%)   | -       | 11                    |
| Ash Content (%)      | 0.01    | 0.009                 |
3. Experimental set-up

In current experimental study, a single cylinder, 4-stroke, direct injection, compression ignition engine was used. Engine load was applied by eddy current dynamometer. Full load capacity of current engine was 3.7 kW. During the experimentation, load was varied gradually at fixed 1500 RPM speed. Inlet air temperature, exhaust gas temperature, cooling water inlet and outlet temperature were measured by using T-type thermocouples. Schematic sketch of test set-up is depicted by figure 1.

![Figure 1. Layout of experimental test-rig](image)

In current research, cotton seed biodiesel and diesel are mixed in different proportions. Biodiesel was blended in diesel under various proportion of 5%, 10%, 15% and 20%.

| Table 2. Specifications of Engine |
|-----------------------------------|
| Engine Type | 4 Stroke CI engine |
| No. of Cylinders | 1 |
| Fuel | Diesel |
| Stroke | 110 mm |
| Bore | 80 mm |
| Cooling medium | Water cooled engine |
| Method of loading | Eddy current dynamometer |
| Compression Ratio | 17:1 |
| Brake Power at full load | 3.7 kW |
| Type of injection nozzle | Pintle |
| Nozzle dia. | 0.3 mm |
| Speed | 1500 RPM |
| Injection Pressure | 190 kg/cm² |
Engine was tested under various loading conditions from no load to full load condition. Diesel fuel termed as D100 was used to get reference data. Exhaust gas analyzer (AVL-444) and Smoke meter (AVL-437) were used to measure emission characteristics of the engine. Engine specifications are as mentioned in Table 2. To achieve steady state condition, engine was operated for 20 minutes at a particular loading condition. All the experiments were repeated three times and average of readings were considered for further analysis. Table 3 shows experimental test matrix.

Table 3. Experimental Details

| Sr No. | Blend type (% vol) | Engine Load | Abbreviation | Injection Pressure (kg/cm²) |
|-------|-------------------|-------------|--------------|---------------------------|
| 1     | Diesel 100%       |             | D100         | 190                       |
| 2     | Diesel 95%, Cotton seed biodiesel 5% |              | D95B5        | 190                       |
| 3     | Diesel 90%, Cotton seed biodiesel 10% | 20%, 40%, 60%, 80%, 100% & 120% | D90B10       | 190                       |
| 4     | Diesel 85%, Cotton seed biodiesel 15% |              | D85B15       | 190                       |
| 5     | Diesel 80%, Cotton seed biodiesel 20% |              | D80B20       | 190                       |

4. Result and discussion

In this experiment, various fuel blends were prepared and engine performance and emission characteristics were examined at fixed speed of 1500 RPM, 30° angle of advance, 190 bar injection pressure, under various loading condition.

4.1. Brake thermal efficiency

Variation in brake thermal efficiency under various loading condition with various fuel blends is depicted by figure 2.

![Figure 2. Brake thermal efficiency vs. brake power](image-url)
It was observed during experiment that brake thermal efficiency at full load condition is higher compared to part load and no load. It was further noted that brake thermal efficiency remains almost unchanged for Diesel, D95B5 and D90B10. Low fuel density of biodiesel and oxygen content present in the biodiesel are two parameters which counteract each other. Brake thermal efficiency has been decreased for D85B15 and D80B20 blends due to lower heating value of biodiesel, high viscosity and volatility. For full load condition, brake thermal efficiency for diesel, D95B5, D90B10, D85B15 and D80B20 blends are 29.7%, 29%, 28.5%, 26.4% and 24% respectively.

4.2. Brake specific fuel consumption (BSFC)
Variation in brake specific fuel consumption under various loading condition with variation in different fuel blends is shown in figure 3. Brake specific fuel consumption remains unchanged for diesel, D95B5 and D90B10 blends due to same reasons discussed above. There is a significance rise in BSFC for D85B15 and D80B20 blends due to lower heating value, high density and high viscosity of biodiesel. At full load condition, percentage rise in BSFC for D95B5, D90B10, D85B15 and D80B20 blends compared to diesel are around 1%, 5%, 24% and 30% respectively.

![Figure 3. Brake specific fuel consumption vs. brake power](image)

4.3. Unburnt HC emissions
Unburnt Hydro-carbon emission confirms the occurrence of unburnt HC present in gas discharging from engine. The major parameters responsible for HC emissions are air fuel ratio, fuel injector design, oxygen content in fuel blend, combustion chamber type, design of injector, kinematic viscosity, spray pattern, and cetane number of fuel. Variation in HC emissions with variation in fuel blend under various loading condition is shown in figure 4. HC emission increases with increase in loading condition. It is further noted that HC emission reduces drastically with increment in percentage biodiesel concentration in base fuel. HC emission is decreased by 1.5%, 3%, 6% and 15% for D95B5, D90B10, D85B15 and D80B20 blends at full load condition.
4.4. CO emissions
Incomplete combustion is responsible for the presence of CO in Exhaust of CI Engine. Improper mixing of air and fuel or lack of oxygen in combustion chamber is the major cause of CO emission. As shown in figure 5, CO emissions found to get decreased with increase in % content of biodiesel in the blend due to oxygen enrichment of fuel. It has been observed that variation in CO emissions with change in fuel blend is more significant at higher loading condition. At full load condition, percentage decrease in CO Emissions for D95B5, D90B10, D85B15, D80B20 compared to diesel are 22%, 30%, 41% and 52% respectively.

Figure 5. CO emissions vs. brake power
4.5. \textit{NO}_x emission

Cylinder temperature, pressure and oxygen presence are the prime factors responsible for NOx emission. Other parameters which affects NOx emissions are cylinder geometry, fuel injector design, fuel atomization, injection pressure, intake air temperature and compression ratio. As shown in figure 6, for all loading conditions, NOx emissions found to be maximum for D80B20 blends compared to other fuel blends. At full load condition, percentage increase in NOx emission for D95B5, D90B10, D85B15 and D80B20 are 6\%, 10\%, 14\% and 22\% respectively.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{nox_emission.png}
\caption{NOx emission vs. brake power}
\end{figure}

4.6. \textit{Smoke density}

Smoke density is one of the important parameters which shows the incomplete combustion inside the engine cylinder.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{smoke_density.png}
\caption{Smoke density vs. brake power}
\end{figure}
Change in smoke density with fuel blends under various loading condition is shown in figure 7. Smoke density at all loading condition found to be maximum for diesel fuel and least smoke emission is found for D80B20 blend. At full load condition, percentage decrease in smoke emission is 8%, 16%, 29% and 46% for D95B5, D90B10, D85B15, D80B20 compared to diesel.

5. Conclusion
In this experiment, a single cylinder, 4-stroke direct injection water cooled diesel engine was used. Engine was tested under various loading condition with different fuel blends. Cotton seed biodiesel was used as alternative fuel and mixed with diesel in different proportions. Experiment was performed at constant engine speed of 1500 RPM. Following points were concluded from the experiment.

(i) Brake thermal efficiency was varying from 10% to 29% with use of various fuel blends under various loading conditions. From the experiment it was found that there was a minor variation in brake thermal efficiency for diesel, D95B5 and D90B10 at any loading condition. For D85B15 and D80B20 blend, there was significant drop efficiency due to lower calorific value of blend compared to diesel.

(ii) From the experimental results, it was further concluded that, CO & HC emission found minimum for D80B20 blend compared to other blends at all loading conditions due to oxygen enrichment of fuel. NOx emission found maximum for D80B20 blends due to same reason.

(iii) Regarding to the performance and emission aspects, D90B10 blends promises good emission characteristics within acceptable range of performance degradation.

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