Experimental investigation of performance, combustion and emission characteristics of CI engine fuelled with turpentine oil – diesel blend, camphor oil – diesel blend, lemongrass oil – diesel blend, mahua oil – diesel blend, karanja oil – diesel blend

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Abstract. Economic and Environment constraint of the developing countries brings them in position to find the new substitute for Fuel which is more economic, ecofriendly, higher efficient and sustainable. Many research was carried in the field of high viscous Biofuel which has been changed into straight oil to Biodiesel to suit the Diesel engine. This project deals with CI engine fuelled with low viscous Biofuel and narrate the characteristics of performance and emissions. This paper deals with Mahua oil – Diesel blend (M50), karanja oil – Diesel blend (K50), Turpentine oil–Diesel Blend (T50), Lemon grass oil – Diesel Blend (L50) and Camphor Oil –Diesel Blend. Low Viscosity and high calorific value of T50 supports for higher thermal efficiency and Lower BSFC when Compare to Diesel, C50, L50, K50 and M50. The High Viscous Biofuels M50, K50 has the Higher CO emissions because of improper. Diesel has the lower HC emission than T50, C50, L50, K50 and M50. Low viscous Biofuel T50 and C50 has lower Smoke emissions and higher Nox emissions. The T50 and C50 has the higher heat release rate and higher peak pressure which supports for proper combustion and results in higher BTE, NOx emissions.

1. Introduction
Skyrocketing requirement of energy because of the increase in vehicles strike the government minds to seek alternate energy. Government was under pressure in order to fulfil the energy demand of people. Impingement of the world emissions scenario add another constraint to government to find the better alternate and clean energy sources. As a result of rapid climatic change, global warming and fossil fuel depletion scientist and researchers are trying to develop alternative source of fuel. The world environmental dilapidation high rate of energy demands leads to process of finding better alternates fuels for Fossil types fuels. India has good resource of Biofuels such as neem oil, mahua oil, karanja oil, cottonseed oil, paradise oil, kapok oil etc but which are underutilized. So it need proper investigation to proceed further either in terms of fuel Economy and Environmental aspects. Biodiesel combustion is complex process compare to the Diesel combustion process which supports in reduction in fewer pollutant and contrast with other pollutant.
Biodiesel supports in carbon dioxide pollutant by maintain the greenhouse gases level or limits. Higher Viscosity, poor cold flow characteristics, grander oxidation Stability was the reason for drawbacks of Biofuels. India has good resource of Biofuels such as neem oil, mahua oil, karanja oil, cottonseed oil, paradise oil, kapok oil etc but which are underutilization [1-6]. So, it need proper investigation to proceed further either in terms of fuel Economy and Environmental aspects. Lump of money was invest by India in order to purchase nearly 80% of Crude oil consumptions. More number of researches was done in the high viscous biofuel either in the form straight fuel or blended fuel or Biodiesel. Still many low viscous biofuel such as lemon grass oil, camphor oil, turpentine oil, Pine oil, eucalyptus oil etc are not still examined well in enough. Low viscous biofuel which is not suffering from drawbacks of viscosity which can used effectively in the Diesel engine.

Pale yellow colour pine oil contains terpineol and pinene with calorific value of the 42.8 MJ/kg, viscosity of 1.3 cST which is comparably good but it suffers from higher auto ignition temperature because of the its lower cetane number [7]. Utilization of pine oil in 50% blending with diesel fuel increase the atomization and oxygen content of the blended fuel and provided the high rate of heat release and has the efficiency in fuel energy into useful work [8]. Increasing the low viscous Camphor oil in cashew nut shell oil decrease the viscosity and density of the blended fuel which contributes in the reduction in physical delay. Camphor oil in cashew shell nut blended fuel supports combustion characteristics and lowering HC and Co emissions when compare to straight cashew nut shell oil [9].

Aromatic grass family lemon grass was mainly found in Tamilnadu, Kerala, Andrapradesh and some parts of India which contains mainly citral which is almost 70% of the total composition. R. Sathiyamoorthi et al [4] found that blending of the Lemon grass oil up to 25% with diesel fuel has increase the brake thermal efficiency, Nox, CO, peak pressure and smoke. Blending of the low viscous Turpentine oil with diesel fuel reduces the relative HC emissions, relative CO emissions, Relative Nox emissions and increase the Relative Nox emissions [10]. Utilisation of the turpentine and jatropha biodiesel diesel engine has higher conversion efficiency of Fuel energy, NOx emissions and Smoke [11]. Pankaj Dubey [13] et al conforms that adding of the turpentine oil with Jatropha biodiesel reduce the Nox emissions because of the longer ignition delay which reduces the combustion durations. Mahua tree is mostly available in northern part of the India which can be grown well in tropical region and it is part of the Sapotaceae Species. Oleic acid, Palmitic acid and Stearic acid are three main compositions of mahua oil [14].

## 2. Methodology

### Table 1. Properties of Biofuels.

| Description               | Diesel | Turpentine Oil | Camphor Oil | Lemon Grass oil | Karanja Oil | Mahua Oil |
|---------------------------|--------|----------------|-------------|-----------------|-------------|-----------|
| Density (kg/m³)           | 830    | 900            | 894         | 910             | 911         | 924       |
| Calorific value (MJ/kg)   | 42.5   | 44.4           | 38.2        | 36.2            | 38.4        | 37.6      |
| Kinematic Viscosity (cST at 40°C) | 4.59  | 2.4            | 1.9         | 4.2             | 27.84       | 24.60     |
| Chemical Formula          | C₁₃H₂₄ | C₁₂H₂₀O₇       | C₁₀H₁₆O     | C₅₁H₈₅O₅       | C₅₄H₁₅₂O₆  | C₅₃H₄₀₇O₆ |
| Molecular weight          | 168    | 276            | 152         | 776             | 846         | 865       |
| Air fuel ratio            | 14.9   | 13.6           | 12.46       | 12.69           | 12.05       | 12.39     |
| C (% by wt)               | 86     | 52             | 78.94       | 78.86           | 76.59       | 76.47     |
| H (% by wt)               | 14     | 7              | 10.52       | 10.8            | 12.05       | 12.39     |
| O (% by wt)               | 0      | 40             | 10.52       | 10.30           | 11.34       | 11.12     |
| C/H ratio                 | 0.52   | 0.6            | 0.625       | 0.60            | 0.52        | 0.51      |
| Cetane Number             | 48     | 38             | 5           | 38              | 39          | 43        |
| Flash point (°C)          | 50     | 38             | 65          | 50              | 230         | 212       |
The fuels were bought from the local suppliers. The five types of fuel were prepared by bending turpentine oil with diesel fuel (T50), Camphor oil with diesel fuel (C50), lemon grass oil with diesel fuel (L50), mahua oil with diesel fuel (M50) and karanja oil (K50) with diesel fuel whose fuel properties are displayed in the Table 1. The experiment was conducted in 4 stroke Diesel engine whose specifications was shown in the Table 2. The engine test conducted at steady state by providing with proper instruments to measure the various parameters. Eddy current dynamometer was engaged with engine to apply the load varying from 0% to 100% of full load. Mass flow rate of the fuel was measured using Fuel flow meter coupled to the Fuel tank. Air flow rate was measured using the air flow meter coupled to air box. In cylinder pressure and temperature was measured using the pressure sensor and temperature sensor provided in the head of the cylinder. Displacement sensor was used to measure the piston position with respect to crank angle. Various temperature sensor was used to measure the engine cooling water temperature and exhaust gas temperature. All the sensors data are collected in computer using Engine soft software with help of DAS systems. The details of measuring instruments are show in the table 3.

| Table 2. Specifications of the engine. |
|---------------------------------------|
| Engine power                          | 5.2 kW @ 1500 RPM                     |
| Cylinder bore, Stroke length,         | 87.5 mm X 110 mm, 17.5               |
| Compression ratio                     |                                        |
| Start of injection and Injection pressure | 23°BTDC and 200 bar                  |
| Temperature sensor                    | K Type thermocouple - RTD            |
| Air flow transmitter                  | Make: Wika Germany                   |
| Fuel flow DP transmitter              | Make: Yokogawa Japan (0-500 mm WC)   |
| Load sensor                           | Strain gauge (load cell: 0-50kg)     |
| Cylinder pressure                     | Piezo sensor (upto 350 bar)           |
| Crank angle sensor                    | Make: Kubler-Germany Model : 8.3700.1321.0360 |

| Table 3. List of measurement uncertainty. |
|-------------------------------------------|
| Measurement     | Accuracy          |
| Speed           | ±10 rpm           |
| Load            | ±10 N             |
| Fuel measurement| ±0.1 cm³          |
| Manometer       | ±1 mm             |
| Time            | ±0.1 s            |
| CO              | ±0.02%            |
| CO2             | ±0.03%            |
| NOX             | ±12 ppm           |
| HC              | ±10 ppm           |
| O2              | ±0.02%            |
| Smoke           | ±1 HSU            |
3. Result and Discussions

3.1. Brake Thermal Efficiency

The variations of the Brake thermal efficiency (BTE) with respect to Brake power (BP) was shown in the figure 2. The Brake thermal efficiency was the function of the mass flow rate of the fuel or else density and calorific value of the fuel and also load acting of the engine. Higher brake thermal efficiency was found for T50 throughout the all loading conditions. Lowest brake thermal efficiency was found for L50 throughout the all loading conditions because of the volume flow rate of the fuel was high due its lower calorific value and higher density in order to produce the same power output. Brake thermal efficiency for C50 was found higher than M50, K50 and L50. M50 has the higher BTE than K50 and L50 because of the joint effect of the density and calorific value. Brake Thermal efficiency for diesel was found higher than blend except T50 and C50. T50 has the higher brake thermal efficiency because of its oxygen content, bigger droplets of fuel and good atomization. Compared to C50, T50 has the lower mass flow rate which favour the fuel to have higher BTE. Lower air fuel ratio requirements of the T50 supports the better combustions and leads to higher Brake thermal efficiency.

3.1.1. Brake Specific Fuel Consumption. Figure 3 shows the variation of the brake Specific fuel consumption with respect with brake power. Brake Specific fuel Consumption (BSFC) was the function of the volume flow rate of the fuel, physical properties such as density and calorific value of the fuel and BTE of the Engine. Higher BSFC was found for L50 followed by K50, M50, C50, D and T50. Higher calorific value of T50 supports for the lower BSFC for that fuel. Lower calorific value and higher density of L50 has higher BSFC when Compare to K50 and M50 even it has higher viscosity. Lower viscosity of C50 Supports for the better combustion with supports of the better atomization. Lower cetane number of C50 has shorter duration of combustion with aid of longer ignition delay which involves the higher rate of the heat release during premixed combustions.
3.2. Emissions

3.2.1. Carbon Monoxide. The figure 4 shows the variation of the CO against the brake power. CO emissions was the function of the incomplete combustion, air fuel ratio either in terms of rich or lean fuel zones and also turbulence. Higher CO emissions was found the M50 which was followed by the K50, L50, D, T50 and C50. Higher CO was found for M50 and K50 because of the slower combustion which leads to longer expansion which results in higher exhaust temperature. Lower rate of pressure rise was the evident for longer combustion in M50 and K50. T50 and C50 has lower Co emissions because of the high rate of pressure rise which leads to better combustion which induces the turbulence which supports the more unburnt fuel to find oxygen for its burning. Heat release rate also higher for the C50 and T50 because of that high heat transfer to unburnt Fuel in combustion to burn faster. The faster combustion rate of the C50 and T50 supports for lower heat rejection to the surroundings which can proved with help of its exhaust gas temperature which was found to be low. Higher combustion temperature of the T50 and C50 assist in good combustion and provide lower CO emission [15].

![Figure 2. Brake thermal efficiency Vs. Brake power.](image)

![Figure 3. Variation of Brake Specific fuel consumption (BSFC) with respect of Brake power.](image)
3.2.2. Unburnt Hydrocarbon. Figure 5 shows the variation of the unburnt HC emissions with respect to brake power. Unburnt HC emissions was the function of the incomplete combustion, air fuel ratio, Hydrocarbon structure of the fuel. Higher Unburnt HC was found for T50 followed by the C50, M50, K50 and L50 and D. AT full load conditions higher Unburnt Hydrocarbon was seen for M50, K50. Lowest Unburnt HC emissions was found for D. Higher heat release rate was found for C50 and T50 which leads to faster expansions and leads to lowering the temperature of the hot gases which results in higher Unburnt HC emissions. Lower exhaust gas temperature of the T50 and C50 states the higher quenching of the hot gases which provides the higher unburnt HC emissions. High viscous M50 and K50 higher Unburnt HC emissions because of the more amount of the fuel was supplied to produce same amount of power to be produced.

3.2.3. Oxides of Nitrogen. The figure 6 shows the variation of NOx the with respect to brake power. The NOx emission was the function of the operating temperature and pressure of the cylinder, oxygen content of the fuel, cetane number of the fuel and duration of the Combustions. The NOx emission was found higher for T50 and followed by the C50, D, L50, K50 and M50. Higher calorific value of the T50 leads to higher rate of pressure rise which supports for higher temperature hot gases formation stimulates the diatomic nitrogen into mono atomic nitrogen which was the reason for higher NOx emissions. M50 and K50 has the lower Nox emissions because of the lower rate of pressure rise. The M50 and K50 has lower flame temperature because of the lower rate of pressure rise because of that it
has lower NOx emissions. For C50, more amount of fuel was burnt in premixed combustion along with more air fuel ratio which enhance the higher NOx formation [15].

The figure 7 shows the variation of the Smoke emissions with respect to brake power. Smoke emission was mainly depending of the air fuel ratio, oxygen content of the Biofuel and bond strength of the carbon to oxygen of the fuel. Lower smoke was found for the T50 followed by C50, D, L50, M50 and K50. High viscous fuel M50 and K50 has higher smoke because of the poor atomization of the fuel particles which slower the rate of oxidation of the fuel produces the higher Smoke when compare to low viscous Biofuel T50, C50 and L50. C50 has the lower cetane number which enhances the turbulence with help of high heat release rate accounting with higher rate of the pressure rise which reduces the smoke emissions for C50 except with T50.
3.3. Air Fuel Ratio

The figure 8 shows the variation of the Air fuel ratio with respect to Brake power. The highest Air fuel ratio was found for T50 followed by C50, D, K50, M50 and L50. Lower density and higher calorific value of the T50 was the main reason for getting higher air fuel ratio. Combustion efficiency was mainly depending air fuel ratio. High viscous M50 and K50 has the lower air fuel ratio because of the higher mass flow rate of the fuel leads to higher CO emission. Excess air found for the T50 and C50 was found to be higher which supports the combustion and also provides the more oxygen for monoatomic nitrogen to react with them to cause the higher NOx emission. Lower A/F of M50, K50 and L50 was one of the main reasons for the higher Smoke emissions for that fuel.

3.4. Exhaust Gas Temperature

The figure 9 shows the variation of EGT with respect to brake power. The Highest Exhaust gas temperature was found for M50 and it followed by K50, L50, and T50 and lowest for the C50. High Viscous M50 and K50 fuel has longer combustion duration and the slower expansion because of that it has higher exhaust gas temperature. The amount of the fuel is burnt for T50 and C50 in pre mixed combustion supports for to faster expansion which supports in higher brake thermal efficiency and lower exhaust gas temperature.

Figure 8. Variation of the Air fuel ratio (A/F) against the Brake Power.

Figure 9. Variation of Exhaust gas temperature (EGT) against the Brake Power.
3.5. In-cylinder pressure and rate of Pressure rise

![Graph showing in-cylinder pressure and rate of pressure rise vs Crank angle at Full load.]

**Figure 10.** In-cylinder Pressure Vs Crank Angle and Rate of Pressure rise vs Crank angle at Full load.

The figure 10 shows the variation of the in-cylinder pressure against crank angle and also variations of rate of pressure rise against crank angle. Lower cetane number of C50 slower the Chemical delay even though it has lower physical delay with help of its lower viscosity and accommodate more amount fuel to burn rapidly in the premixed combustion and leads to higher rate of pressure rise and highest in cylinder or combustion peak pressure. The T50 also has the higher In cylinder Peak pressure because of the higher calorific value of the fuel which produces more amount of heat which supports for good rate of pressure rise. High Viscous M50 and K50 has lower in cylinder peak pressure of its higher viscosity. L50 also has the moderate Peak pressure because of the lower energy density. M50 has the lowest in cylinder peak pressure of 68.18 bar and C50 has the highest in cylinder peak pressure of 78.6 bar.

3.6. PV Diagram

Figure 11 shows the actual PV diagram for the all the fuels. The maximum peak pressure was found higher C50 and T50 and it also higher rate expansion compare to diesel fuel and assist for high thermal efficiency. The rate of pressure rises for M50 and K50 lower than all fuel and it also has lower expansion rate which lower BTE. The physical delay of the M50 and K50 was found higher and leads to longer expansion and also provides more amount for fuel to burn in the controlled combustion stages which leads to higher CO and EGT.

![Graph showing PV Diagram at Full load.]

**Figure 11.** PV Diagram at Full load.
Net heat release rate
\[ \frac{dQ}{d\theta} = \frac{y}{y-1} \frac{dp}{d\theta} + \frac{1}{y-1} \frac{dV}{d\theta} \]  
(1)

The Net heat release rate was calculated using equation 1 and shown in the figure 12 for all the fuel. C50 has the higher heat release rate and followed by T50, L50, D, K50 and M50. C50 has the high heat release rate because of the Low cetane number. T50 has high heat release rate because of the high calorific value of the fuel. M50 and K50 has the Lower heat release rate of the longer physical delay. L50 has the moderate heat release rate because of its low calorific value of the fuel.

![Figure 12. Net heat release rate Vs Crank Angle at Full load.](image)

3.7. Cycle Variation
The maximum in cylinder pressure (Pmax) for 100 cycles for all fuels are shown in the figure 13. 100 cycles of the C50 and T50 was found higher than Diesel, L50, K50 and M50. High viscous M50 and K50 has lower Pmax for all 100 cycles. L50 has low viscosity but even though it has lower Pmax because of the lower rate of pressure rise compare T50 and C50. COV, RANGE, STDEV, UED OF Pmax calculated. COV was found lowest for T50 followed by Diesel, M50, K50, C50 and L50. Range of Pmax was found higher for L50 followed by C50, K50, T50, M50 and diesel fuel. UED was found higher for L50 and followed by K50, C50, M50, T50 and Diesel fuel. The Pmax was found minimum for M50 because of the longer combustion duration. T50 has lower cycle variation because of the moderate Cetane number, higher calorific value and lower viscosity.

![Figure 13. Pmax for 100 cycles vs number of cycles at Full load.](image)
4. Conclusions

The experiment results were examined and following conclusions were made.

The BTE was found higher for T50 because of the higher calorific value, lower viscosity and moderate cetane number which supports for better combustions. The low viscous biofuel M50 and K50 has the lower BTE because of the longer physical delay period. L50 has lower BTE because of the low calorific value and higher viscosity.

The BSFC was found higher for low calorific value fuel L50, K50 and M50. The lower BSFC was found for T50 when compare to all Biofuel and Diesel. Even though the C50 has lower cetane number which was compensated by the lower viscosity which supports for better combustion. Hence it also higher BTE but lower than T50.

The CO emission was found higher for the M50, K50 because of the lower turbulence created by lower rate of the pressure rise. High rate of heat release combined with high rate of the pressure rise supports for better combustions which results in lower CO emissions for C50 and T50.

High unburnt HC emissions was found for the T50 and C50 because of the quenching effect caused by the reduction of temperature of hot gases due to high rate of expansion. At full load, Unburnt HC emission was found higher for K50, M50 and L50 because of the absence of the excess oxygen available for fuel combustions.

NOx emissions was found higher for T50 because of the higher calorific value and moderate cetane number which supports for high temperature hot gases productions. M50 and K50 has lower NOx emissions because of slower combustion.

Smoke emission was found higher for M50 and K50 because of the lower rate of pressure rise. T50 and C50 has the lower smoke emissions because of the good utilization excess oxygen during premixed combustion.

The maximum in cylinder peak pressure was found for T50 and C50 which supports for higher BTE. Higher heat release rate and pressure rise rate was found for T50 and C50. The cycle variations was found lower for T50 because of the higher calorific value, Low density and moderate cetane number.
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