Experimental Investigation on the Performance Characteristics of Compression Ignition Engine Fuelled with Various Blends of Calophyllum Inophyllum Biodiesel

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Abstract - *In the present study, an experimental work had been carried out to analyze the Performance characteristics of compression ignition engine fuelled with various blends of Calophyllum Inophyllum biodiesel. The engine tests are conducted on kirloskar, 5.2 kW, 4-stroke, single cylinder, 1500 rpm, water cooled, direct injection diesel engine with eddy current dynamometer with injection timing 23° bTDC and injection pressure 210 bar were maintained constant throughout the experiment. Different blends of Calophyllum Inophyllum biodiesel such as B20, B40, B60, B80 and B100 are prepared to analyze the Performance characteristics.*

Key Words: Calophyllum Inophyllum biodiesel, Blends, Performance, Engine.

1. INTRODUCTION

Increasing number of automobiles has led to increase in demand of fossil fuels (petroleum). The increasing cost of petroleum is another concern for developing countries as it will increase their import bill. The world is also presently confronted with the problem of fossil fuel depletion and environmental degradation. Fossil fuels have limited life and the ever increasing cost of these fuels has led to the search of alternative renewable fuels for ensuring energy security and environmental protection. Biodiesel as a vegetable oil, biodegradable and nontoxic, has low emission profiles and so is environmentally beneficial. Biodiesel is a chemically produced vegetable oil to replace the traditional diesel fuel. The chemical process is known as transesterification and consists of treating vegetable oils, like soybean, sunflower and rapeseed, with reactants (methanol or ethanol) to obtain a methyl or ethyl ester and glycerine. The reaction is catalyzed by a reaction with either an acid or base and involves a reaction with an alcohol, typically methanol if a biodiesel fuel is the desired product. Arun B. [1] found that, BTE of all blends were constantly increased based on the load condition and B40 had higher BTE. B10 had higher Mechanical efficiency at various loads but at the full load condition B20 had the higher efficiency than the B10. Fuel Consumption had increased in all load condition for diesel fuel. Among all other blends, B10 had the lower fuel consumption rate. B10, B20 had lower CO emissions when compared with petroleum diesel at full load. The CO_2 emissions for all blends except B40 were less as compared to diesel at all loads. Increased the blend percentage of Tamanu oil decreased the UBHC emissions. All the blends had lower UBHC emissions after about 75% load. Among the blends, B30 had lower UBHC emissions. NOx emissions for all blends were less as compared to diesel at all loads. With increased the percentage Tamanu blends there was a trend of decreased NOx emissions. The EGT increased with increase in load for all blends. Among the blends B30 had the lowest EGT than diesel. Mohan T. Raj et al. [2] found that, the SFC decreased with the increase in compression ratio. SFC was found to be lower at a compression ratio of 18. The SFC of the esterified Tamanu oil at the compression ratio of 18 was 0.24 kg/kW-hr, whereas at the compression ratio of 14, it was 0.29 kg/kW-hr for maximum load. The BTE of biodiesel was slightly higher at the compression ratio of 16 and lower at the compression ratio of 18. The BTE of the esterified Tamanu oil for the compression ratio of 18 was 30.4% at maximum load. The variation in the volumetric efficiency was comparably less for all range of compression ratios and it was high at compression ratio 18. The volumetric efficiency of esterified Tamanu oil for compression ratio of 18 was 62.91% at maximum load. The variation in exhaust gas temperature was very minimal when the compression ratio was varied from 14 to 18. The highest temperature obtained was 446.35°C at the compression ratio of 14 and 430.5°C at compression ratio of 18 at maximum load. The delay period was consistently low for esterified Tamanu oil by increasing the compression ratio from 14 to 18. The delay period was 8° crank angle (CA) at the compression ratio of 14 and 6° CA at 18 for maximum load. The peak pressure increased linearly from 64 to 81 bar as the compression ratio increases from 14 to 18 for maximum load. The rate of pressure rise decreased when the compression ratio was increased from 14 to 18. The duration of injection was 38° CA at the compression ratio 14 and 34° CA at compression ratio 18 for maximum load. The combustion duration was 40° CA at the compression ratio of 14 and 43° CA at the compression ratio of 18 for maximum load. The smoke intensity was 3.9 HSD at the compression ratio of 14 and 3.4 HSD at the compression ratio of 18 for maximum load. The CO emission of the esterified Tamanu oil was found to be lower for high compression ratio of 18 and it was 0.18% at maximum load. The CO_2 emission was 3.3% at the compression ratio of 14 and 5.1% at the compression ratio of 18 for maximum load. The HC emission was 152 ppm at the compression ratio 14 and 125 ppm at the compression ratio of 18 for maximum load. The NOx emission for esterified Tamanu oil was higher with the increase in compression ratio. The NOx emission for esterified Tamanu oil at the compression ratio of 18 was 201 ppm at maximum load. The particulate emission decreased with the increase in compression ratio from 14 to 18 for all loads. The particulate emission was 1900 mg/m^3 at the compression ratio of 14 and 1600 mg/m^3 at the compression ratio of 18 for maximum load. P. Navaneetha Krishnan et al. [3] found that, as the applied load increased the BTE of the fuel blends also increased. The maximum BTE at full load was 41.72% for B40. The BTE of B20 and diesel were 39.68% and 36.49% respectively. When the load increased the specific fuel consumption of the fuel will maintain a gradual decrease. The specific fuel consumption values were 0.2234 kg/kW-hr, 0.2268 kg/kW-hr and 0.2201 kg/kW-hr for the fuel blends B20, B40 and diesel respectively. The fuel blends B10, B20, B40 and B60 had decreased BP while comparing with standard diesel. The BP values were 3.7149 kW and 3.6973 kW for B40 and standard diesel respectively. The indicated mean effective pressure for blend B40 and standard diesel at 50% load was 1.908 bar, 1.919 bar and for 75% load was 2.834 bar and 2.841 bar respectively. As the load increased, mechanical efficiency for all the blends were also increased. Blends B40 and B10 at full load were had maximum mechanical efficiency and it was 93.77% and 87.62% respectively. Exhaust gas temperature decreased for different blends when compared to that of diesel. Standard diesel had highest exhaust gas temperature and it was 323.97°C, whereas the blends B20 and B40 were had lower temperature 306.23°C and 312.93°C respectively. The Tamanu oil blend B40 gave higher combustion pressure. The peak pressure values for standard diesel and Tamanu oil blends B10, B20, B40 and B60 were 72.89 bar, 73.07 bar, 70.76 bar, 71.30 bar and 69.16 bar respectively, at full load. The combustion duration for the fuel blends B10, B20, B40, B60 and diesel at full load condition were 36.37, 35.38, 34.17, 29.85 and 38.94° CA respectively. The maximum heat release rate for blends B10, B20, B40, B60 and diesel were 17.23, 17.61, 17.45, 16.10, 17.92 J/° CA. The heat release rate decreased at the start of combustion and increased further. The heat release rate of Tamanu oil blends decreased compared to diesel at full load. At crank angle 340°-360°, the mass fraction burnt for the fuel blend B40 was higher than diesel. At crank angle 360°-390°, the mass fraction burnt was slightly closer to each other. The ignition delay decreased with biodiesel in the diesel blends with increase in load. The ignition delay period for B10, B20, B40 and B60 at full load conditions was 5.34, 1.61, 3.68 and 3.39°/CA respectively. At higher load condition the HC emission of various blends were higher except the blend B20. For blend B40 increase in load increase the HC emission. The other blends B10, B20 and B60 produced lesser HC emission at 50% and 75% load while compared with diesel. The NOx emission for diesel was lower than that of biodiesel and its blends except B40 at lower loads. For 50% load, NOx emission from Tamanu oil blend B40 was slightly lower than that of diesel. At 100% load condition, the NOx emission from B40 blend was higher than that of diesel. The NOx emission for fuel blend B40 and diesel for 50% load was 18 ppm and 22 ppm respectively. R. Rajappan et al. [4] found that, the specific fuel consumption of the esterified Tamanu oil blend B20 at the compression ratio of 18 was 0.24 kg/kW-hr and for B60 was 0.28 kg/kW-hr at maximum load. The BTE of the diesel engine was reduced at higher concentration of biodiesel blends. The BTE of B20 was higher than pure diesel. The BTE of the esterified Tamanu oil for the compression ratio of 18 and B20 was 32.6% at maximum load. The CO emission of the esterified Tamanu oil was found to be lower for high compression ratio of 18 and B60 blend was 0.06% at maximum load. The HC emission of diesel was 44 ppm at the compression ratio of 18 and for blend B60 was 30 ppm for maximum load. NOx emission for esterified Tamanu oil at compression ratio of 18 and for blend B40 was 500 ppm at maximum load. There was significant reduction in the smoke opacity with increase in biodiesel concentration. G. Deepankumar [5] found that, the maximum BTE obtained was about 30% for B15, which was higher than that of diesel. Among the blend B15 was had specific fuel consumption lowest at all loads. B100 had higher mechanical efficiency at all load condition. Smoke density increased with increase in load and B100 produces more smoke at all load condition. At low loads, the CO emission for B15 and diesel were found to be same but at higher loads, B15 produced more CO. the blend B15 gives less CO_2 emission at full load condition. Oxygen emission tends to decreased with the increase in load. HC emission tends to increase with the increase in load. Almost all blends gave higher HC emission than that of diesel. The NOx emission increased as the engine load increased. All blends produced lower NOx compared to diesel over entire load range. B100 gave less NOx over entire load range. The exhaust gas temperature tends to increase with increase in brake power. All blends gave low exhaust gas temperature when compared to that of diesel. Murugan K. et al. [6] found that, for all fuels tested BSFC was found to decrease with increase in the load. Using lower percentage of biodiesel in biodiesel-diesel blends, the BSFC of the engine was lower than that of diesel. The specific fuel consumption of Calophyllum Inophyllum oil was higher than that of diesel. BTE had the tendency to increase with increase in applied load. The maximum BTE obtained was about 28% for B20, which was higher than that of diesel. CO emissions were decreased as the load increases. NOx emissions were low for B20 fuel than diesel at low and medium loads but emissions were higher than diesel at maximum load condition. M. Parthasarathy et al. [7] found that, the BTE increased with higher enrichment of acetylene. A higher BTE of 29.69% was achieved by diesel at full load. The BTE of TME-20 and TME for acetylene enriched air were 28.87% and 25.12%

respectively. The specific energy consumption of TME-20 decreased from 19.87 MJ/kW-hr to 12.46 MJ/kW-hr, when 4 lpm of acetylene enriched air was introduced in the combustion of biodiesel; it slightly increased by 8.06% compared to neat diesel. When the mass flow rate of acetylene enriched air of 4 lpm with TME-20 was injected at full load condition, NOx emission increased from 80 ppm to 480 ppm, compared to neat diesel, it showed in an increase of 11%. CO emission was recorded as 0.12%, 0.113%, 0.105%, 0.122% and 0.11% with diesel, TME-20, TME-40, TME-60, TME-80 and neat TME respectively, at full load condition. Ashish G. Bandewar et al. [8] found that, for full load condition, when the compression ratio was varied from 14.5 to 17.5, the highest CO emission found was 1.054% for diesel, 1.585% for H25, 1.938% for H50 and 1.905% for H75, all were at the compression ratio of 14.5. The lowest CO emission found was 0.365% for diesel, 0.06% for H25, 0.066% for H50 and 1.187% for H75; all were at the compression ratio of 17.5. The CO emissions were higher at lower compression ratio and decreased at higher compression ratio. The CO emissions for biodiesel and its blends were higher, compared to diesel over entire range of fuel blends, except H25. The biodiesel and its blends emitted lower percentage of CO_2 as compared to diesel at higher compression ratio. For full load condition, the highest CO_2 emission found was 4.47% for diesel with lowest emission found was 0.4% for H25, 2.86% for H50 and 3.19% for H75 all were at the compression ratio of 17.5. The lowest CO_2 emission found was 1.96% for diesel, with highest emission found was 5.04% for H25, 3.75% for H50 and 4.32% for H75; all were at the compression ratio of 14.5. For full load condition, the highest HC emission found was 103 ppm for diesel at compression ratio 15.5 and 100 ppm for H25, 214 ppm for H50 and 235 ppm for H75, all were at compression ratio 16.5. The lowest emission obtained was 34 ppm for diesel, 10 ppm for H25, 89 ppm for H50; all were at compression ratio 17.5, but 142 ppm for H75 at compression ratio 16.5. The NOx emission for entire range of fuel was higher at the compression ratio 15.5. For full load condition, the highest NOx emission found was 430 ppm for diesel at compression ratio 17.5 and 419 ppm for H25, 611 ppm for H50 and 629 ppm for H75, all were at compression ratio 15.5. The lowest emission found was 166 ppm for diesel at compression ratio 14.5, 89 ppm for H25 at compression ratio 17.5 and 250 ppm for H50, 301 ppm for H75 both at compression ratio 14.5. Rahul Krishnaji Bawane et al. [9] found that, there was a steady increase in brake thermal efficiency as compression ratio increases. Biodiesel and its blends resulted in decreased brake thermal efficiency as compared to diesel over the entire range of compression ratio. The brake specific fuel consumption (BSFC) decreased with the increase in compression ratio. BSFC for biodiesel and its blends were higher than that of diesel. When the compression ratio was increased, EGT decreased. The CO emission of the biodiesel and its blends were found to be lower for high compression ratio. The CO emissions for biodiesel and its blends were higher, compared to diesel over the entire range of fuel blends, except H25. The biodiesel and its blends emit lower percentage of CO_2 as compared to diesel at higher compression ratio. CO_2 emissions of H25 blend showed highest CO_2. The HC emission decreased with increase in compression ratio for the entire range of fuels. The NOx emission for entire range of fuel was higher at the compression ratio 15.5. Highest NOx emission obtained at highest compression ratio 17.5. The O_2 emission increased continuously with increase in compression ratio. Biodiesel and its blends showed higher O_2 emission as compared to diesel for full load conditions.

1.1 Calophyllum Inophyllum oil

Scientific name – Calophyllum inophyllum
Other names – Punnai, Tamanu, Kamani.

Fig-1: Tamanu fruits

Fig-2: Tamanu seed's shell and kernel

2. TRANSESTERIFICATION REACTION

It is most commonly used and important method to reduce the viscosity of vegetable oils. In this process triglyceride reacts with three molecules of alcohol in the presence of a catalyst producing a mixture of fatty acids, alkyl ester and glycerol. The process of removal of all the glycerol and the fatty acids from the vegetable oil in the presence of a catalyst is called esterification.

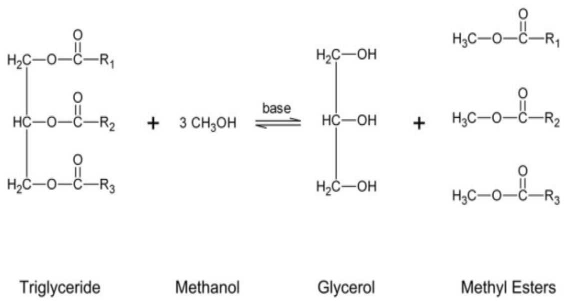

Fig-3: Transesterification reaction

The first step for biodiesel preparation is the transesterification of vegetable oils. By this process the molecular size of the component (triglycerides) reduces. Such that the resultant esterified oil could be used in diesel engine for a prolonged period without any serious issues like carbon buildups, scum formation, etc. The transesterification process is as follows: one liter of raw oil was taken in a round bottom flask and was heated up to 110°C in order to remove the moisture content present in it. Base catalyst NaOH (7.5 g approx.) was dissolved in methyl alcohol (300 ml) and maintained at the reaction temperature of around 65°C for a period of 60 minutes. The reaction products were allowed to settle under gravity in separating funnel for 24 hours to separate methyl esters and glycerol. Due to the higher density of glycerol it settled at the bottom of the funnel and obviously methyl esters occupied the top surface. The methyl ester was then washed with warm water to remove un-reacted methanol, catalyst and impurities. The washed methyl ester was again heated to 110°C to remove the moisture content. Various biodiesel-diesel blends (B20, B40, B60, B80 and B100) were prepared for the experimental work.

3. PROPERTIES OF FUELS

Table-1: Properties of Calophyllum Inophyllum biodiesel blends compared with diesel

Properties	B0	B20	B40	B60	B80	B100
Density (kg/m^3)	827	840	854	867	881	894
Kinematic Viscosity at 40°C (cSt)	3.517	3.985	4.452	4.918	5.387	5.86
Flash Point (°C)	52	75	98	122	149	168
Fire Point (°C)	59	84	108	135	159	184
Calorific Value (MJ/kg)	42.21	41.68	41.15	40.62	40.09	39.56

4. EXPERIMENTAL SETUP

Fig-4: Engine setup

A single cylinder, direct injection, four-stroke, water-cooled, Compression Ignition (CI) engine is used in the experimental study. The technical specification of the engine is given in Table-2. The engine was loaded by eddy current dynamo meter. The fuel flow rate was measured by noting down the time taken for the consumption of a known quantity of fuel (10cc) from a burette. The viscosity of raw as well as esterified oil was measured by red wood Viscometer, density by hydrometer, calorific value by bomb calorimeter, flash and fire point by open cup method. Initially, before starting experimental tests, the engine was made to run under ideal condition as warm up phase and then the tests were conducted. The engine was started and allowed to warm-up for about 10 minutes. The engine was tested under five discrete part load conditions i.e. 20%, 40%, 60%, 80% and 100%.

Table-2: Engine specifications

Engine Parameter	Specifications
Engine Type	Kirloskar
No. of Strokes	4
No. of Cylinders	1
Type of Cooling	Water Cooling
Type of Injection	Direct Injection
Bore	87.5 mm
Stroke	110 mm
Compression Ratio	17.5:1
Rated Power	5.2 kW
Rated Speed	1500 rpm
Injection Pressure	210 bar
Injection Timing	23° bTDC

5. RESULTS AND DISCUSSION

5.1 Brake Thermal Efficiency (BTE)

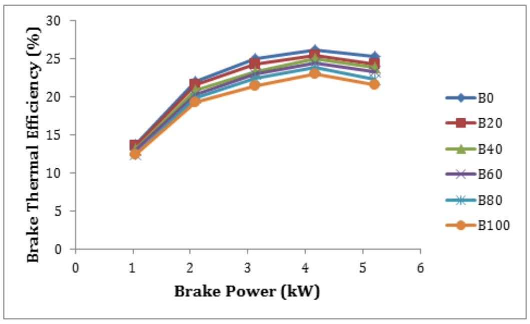

Fig-5: Variation of BTE with BP for different biodiesel blends

Variation of BTE with BP for different biodiesel blends as shown in Fig-5. For all the fuels tested the Brake Thermal Efficiency increases with increase in load. This is due to, reduction in heat loss and increase in power with increase in load. The Brake Thermal Efficiency of biodiesel blends was found to be lower compared to diesel at all power output. This is due to, the lower calorific value, higher viscosity, higher density which leads to poor atomization of biodiesel than diesel which results into increase of Brake Thermal Efficiency for diesel than biodiesel blends. At 80% load condition all tested fuels give higher Brake Thermal Efficiency than at 100% load condition. This is due to the fact that, the power produced from the engine is less than the amount of fuel consumed to develop that power at 100% load condition so that Brake Thermal Efficiency decreases at 100% load condition as compared to 80% load condition.

5.2 Brake Specific Fuel Consumption (BSFC)

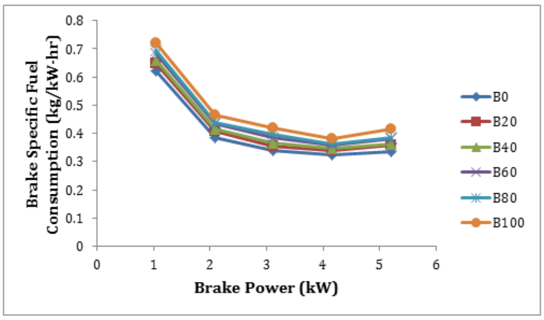

Fig-6: Variation of BSFC with BP for different biodiesel blends

Variation of BSFC with BP for different biodiesel blends as shown in Fig-6. As the load increases Brake Specific Fuel Consumption decreases. It is observed that Brake Specific Fuel Consumption for blends of biodiesel blends is higher when compared with diesel. For effective burning of the fuel the calorific value of the fuel should be higher so that the evaporation of the fuel is also high. The calorific values of blends of biodiesel are lower when compared with diesel; hence the fuel evaporation is slower. Slower evaporation rates leads to higher brake specific fuel consumption.

5.3 Total Fuel Consumption (TFC)

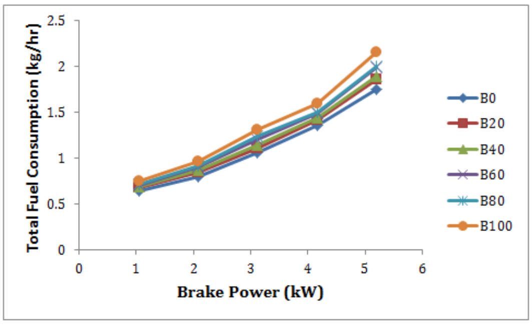

Fig-7: Variation of TFC with BP for different biodiesel blends

Variation of TFC with BP for different biodiesel blends as shown in Fig-7. As the load increases Total Fuel Consumption increases for all fuels tested. Total Fuel Consumption for diesel is less as compared to biodiesel blends. This is due to higher viscosity, higher density which leads to higher fuel consumption of biodiesel than diesel.

6. CONCLUSION

The Brake Thermal Efficiency of biodiesel blends was found to be lower compared to diesel at all power output. Total Fuel Consumption for diesel is less as compared to biodiesel blends. Brake Specific Fuel Consumption for blends of biodiesel blends is higher when compared with diesel. Among the biodiesel blends tested, B20 gave the best performance with reduced emissions. The BTE of the engine with the B20 blend at 80% power output which is closer to diesel operation. Hence B20 blend is recommended for existing diesel engine.

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