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Experimental Investigation of Calophyllum Inophyllum Methyl Ester biodiesel blends as an alternate fuel for diesel engine

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Abstract: **Calophyllum Inophyllum Methyl Ester oil is a great evergreen tree commonly found in Africa, Madagascar, Papua New Guinea, India, Northern Australia, and America, the Peninsula, islands of the Pacific Ocean, Melanesia and Polynesia, and the tropics of Asia. Calophyllum Inophyllum Methyl Ester oil is non-edible in nature but it can be used as a source of biodiesel. In India and other countries, it is available in enough quantities. The Calophyllum trees are found in India which can reduce the dependency of petroleum imports to a certain limit. The present research work has shown the suitability of Calophyllum Inophyllum Methyl Ester as a suitable feedstock for biodiesel production. The biodiesel Calophyllum Inophyllum Methyl Ester and its blends are used in engine testing. The experimental parameters such as brake thermal efficiency, brake specific energy consumption, unburned hydrocarbon, carbon monoxide, and NOx emissions are evaluated with Calophyllum Inophyllum Methyl Ester biodiesel and the results are compared with Diesel.**

IndexTerms **– Calophyllum Inophyllum Methyl Ester, Biodiesel, Performance analysis, Transesterification, Diesel Engine.**

I. Introduction

Rapid growth in population, as well as urbanization, increases the energy demand. The continuous reduction of conventional petroleum-based oil reserves also rapid degradation in air quality are continuously motivating researchers to find more sustainable, suitable, and cleaner energy sources.[1]. As a result, biodiesels produced from vegetable oil as feedstocks are receiving significant attention as an alternate option to fossil-based diesel. In 1937 the first recorded production of biodiesel occurred in which palm oil is used as feedstock [2].

Biodiesel is an alternate energy source on which several investigations had been done in previous years. It is mainly produced from vegetable oils such as cottonseed, corn, sunflower, peanut, safflower, coconut, or palm, waste cooking oils, or animal fat. These are then chemically reacted with alcohol in different proportions and can be directly used in diesel engines without changing or modifying the engine design and specification [3]. It is found that there are about 300 varieties of oil seeds but only 10-15 varieties have been tapped so far, amongst which "Oleander", "Bitter Groundnut" and "Kusum", the non-edible vegetable oils can be considered as a potential alternative fuel for CI engines [4].

Long-chain hydrocarbons have good ignition characteristics, but they can cause serious problems like carbon deposit buildup, poor durability, high density, high viscosity, lower calorific value, more molecular weight, and poor combustion. These problems lead to poor thermal efficiency [5]. These problems can be rectified by different methods that are used to reduce the viscosity of vegetable oils. The different methods are transesterification, dilution, and cracking method. The transesterification of vegetable oil gives better performance as compared to straight vegetable oil [6].

Transesterification is where an ester is transformed into another by an interchange of the alkoxy radical group. Transesterification involves stripping glycerin from fatty acids with a catalyst such as sodium or potassium hydroxide and replacing it with anhydrous alcohol which is usually methanol [7]. However, potassium hydroxide is considered the best catalyst for the transesterification of all types of vegetable oils. There are four transesterification processes for the formation of biodiesel from oils and fats. (i) Base-catalyzed transesterification. (ii) Direct acid-catalyzed transesterification. (iii) Enzyme catalytic conversion of the oil into fatty acids and then into biodiesel. (iv) Non-catalytic transesterification using methanol or methanol. The base-catalyzed transesterification of vegetable oils with simple alcohol has long been the preferred method for producing biodiesel. As Methanol is the most commonly used alcohol because of its low cost [8].

Biodiesel has a higher cetane number than petroleum diesel fuel and has no aromatics. Also contains 10% to 11% oxygen by weight. Because of these characteristics, biodiesel reduces the emissions of CO, UHC, and PM in the exhaust gas compared with diesel fuel [9]. Ong et al. 2014, reported an optimum yield of Calophyllum Inophyllum Methyl Ester biodiesel at a 9:1 methanol to oil ratio with 1% wt. NaOH catalyst at 50ºC for 2h. The performance and emission of 10% Calophyllum Inophyllum Methyl Ester biodiesel blends (CIMEB10) gave a satisfactory result in diesel engines [10].

The main biodiesel production challenge in commercialization is the high cost of production of biodiesel as compared to fossil fuel diesel. This is due to that the cost required in producing biodiesel heavily depends on feedstock cost or raw materials from which biodiesel is to be extracted. The higher feedstock production costs are in turn due to high prices of inputs including fertilizer and energy, low recovery of biofuel from feedstock, and availability of a narrow range of inputs for biofuel production [11].

Calophyllum Inophyllum Methyl Ester seed is one of the easily cultivable and widely available feedstocks for biodiesel transesterification in developing countries like India. Only very few research works have been carried out in implementing 100% Calophyllum Inophyllum methyl ester and blend as an alternative fuel for diesel. The kinds of literature have not arrived at a systematic investigation for deploying 25%, 50%,75%, and 100% Calophyllum Inophyllum Methyl Ester with diesel in a CI engine. Hence, the present research work aims at focusing on the performance, emission, and combustion characteristics of diesel engines fuelled with various blends of Calophyllum Inophyllum methyl ester with 25% CIME, 50% CIME, 75% CIME, and 100% CIME. The experimental results have been compared with conventional diesel fuel. Certain important parameters such as brake-specific energy consumption, brake thermal efficiency, unburned hydrocarbons, carbon monoxide, carbon dioxide, oxygen, NOx emissions, and Exhaust gas temperature are evaluated for variable compression ratio. [12-15].

II. Materials

Calophyllum Inophyllum Methyl Ester oil was collected from the authorized manufacturer.
Variable Compression Ratio Diesel engine setup.
Diesel, Temperature Bath, Reaction Flask with a reflux condenser, and rpm-controlled magnetic stirrer.
Potassium Hydroxide as catalyst and methanol.

III. Biodiesel Preparation

Calophyllum Inophyllum Methyl Ester oil is used for the preparation of biodiesel shown in Fig.1. The most common method used to reduce the viscosity of vegetable oil to produce biodiesel is by trans-esterification. Triglyceride (TAG) consists of three esters of fatty acid chain attached to glycerol. Glycerol is part of Triglyceride which contributes to the high viscosity of vegetable oil. The free Fatty Acid (FFA) part is 10 times less viscous than vegetable oil. Triglyceride is a type of ester. the reaction which converts Triglyceride into biodiesel is known as the trans-esterification reaction. The process of transesterification is shown in Fig. 2 for the biodiesel extraction.

Fig.1 Extraction processes of Calophyllum inophyllum oil

It is crucial that feedstock used in alkali-catalyzed trans-esterification should contain free fatty acids (FFA). The Free Fatty acids in the feedstock can significantly affect the ester yield and glyceride conversion in the alkali-catalyzed transesterification process. Higher the acidity of the oil, the lower the yield and conversion rate. If Free Fatty acids content is more, extra alkali is needed to neutralize the Free Fatty acids. Also, it will cause soap formation.

Step 1:- Esterification of Calophyllum Inophyllum Methyl Ester oil with an acid catalyst to produce ester

In Step 1 the fatty acid is esterified with methanol and acid catalyst to produce ester. The conversion efficiency of biodiesel yield and production depends upon the molar ratio of alcohol to oil. Also, it increases the miscibility and improves the contact between alcohol and tri-glyceride. Even though the excess amount of alcohol enhances the biodiesel purity. The optimum conditions for the reactants were found to be a 16:1 methanol-to-oil ratio. An acid Catalyst is used in a ratio of 10 ml of H_2SO_4 for 100 ml of oil. The reaction temperature is set to 60^0C for 45 min of reaction time. The magnetic stirrer is used to provide constant stirring.

Step2:- Trans-esterification with an alkali catalyst

In Step 1 fatty acid was converted to ester. Now in Step 2, we use an alkali catalyst for the trans-esterification process. The optimum conditions for the reactants were found to be a 16:1 methanol-to-oil ratio. The Alkali catalyst was used with a 0.5 g concentration of Sodium hydroxide for 100 ml of oil. Again the reaction temperature is maintained at 60 ^0C for 30 min of reaction time. The magnetic stirrer is used to provide constant stirring.

Step3 :- Purification

In Step 3 Purification is done by removing methanol by heating biodiesel at 75 ^0C for about 30 min to remove trapped methanol.

Step4 :- Separation

After the purification of biodiesel, the last step is used to separate the biodiesel and by-product. In this step, Biodiesel Mixture is poured into the Separatory funnel. The mixture is allowed to settle down. After Some time, the biodiesel and the by-product get separated in terms of the layers. The physical and chemical properties of Calophyllum Inophyllum Methyl Ester have been evaluated and compared with diesel which is presented in Table.1

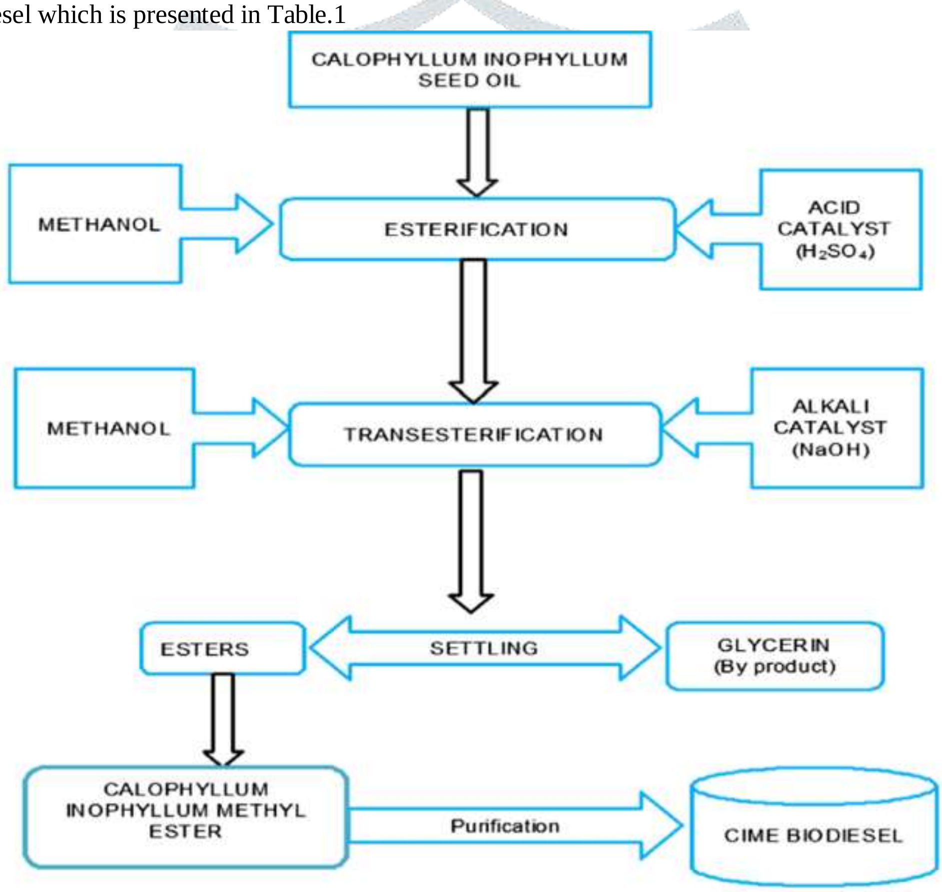

Figure.2 Transesterification process of Calophyllum Inophyllum biodiesel [16]

Table.1 Physical and chemical properties of fuels [17]

Fuel properties	**Units**	**Diesel**	**Calophyllum Inophyllum Methyl Ester**
Acid number	mg of KOH/g	-	0.39
Sulfated ash	wt.%	-	0.001
Methanol content	wt.%	-	0.02
Flash point	^0C	53	170
Kinematic viscosity at 40 ^0C	mm^2 /s	2.30	5.4
Density at 15 ——————————————C	kg/m^3	824	870
Calorific value	MJ/kg	42.5	37.9
Cetane index	-	39	59.5

IV. Experimental Setup

The setup consists of a single-cylinder, four-stroke, VCR (Variable Compression Ratio) Diesel engine with specifications given in Table.2 connected to an eddy current-type dynamometer for loading. The compression ratio can be changed without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement.

The Setup is provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced with the computer through engine indicators for diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures, and load measurement. The setup has a stand-alone panel box consisting of an air box, two fuel tanks for duel fuel tests, a manometer, a fuel measuring unit, transmitters for air and fuel flow measurements, a process indicator, and an engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement.

The setup enables the study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, and heat balance.

Table.2 Specifications of The Engine Used for Testing

Parameters	Specification
Number of Cylinders	1
Number of Strokes	4
Fuel	H.S. diesel
Rated Power	3.5 Kw
Stroke Length	110mm
Cylinder Diameter	87.5mm
Connecting Rod Length	234mm
Compression Ratio	17.5:1
Orifice Diameter	20mm
Dynamometer Arm Length	185mm

Figure 3 Experiment test setup used for testing the biodiesel

V. Result and Discussion

The engine is started and allowed to warm up for some time. The performance, combustion, and emission data are obtained at various loads of 0%, 25%, 50%, 75%, and 100%. The different parameters like Brake Thermal efficiency, Brake Specific Fuel Consumption, Exhaust Gas Temperature as well as CO Emission, HC Emission, CO2 Emission, O2 Emission, and NOX Emission are evaluated.

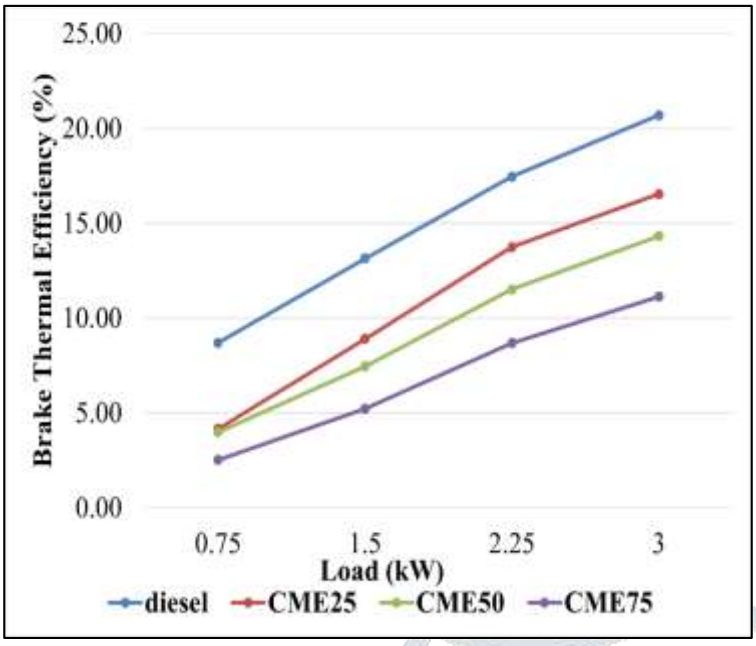

Figure.4 Brake Thermal Efficiency VS Load

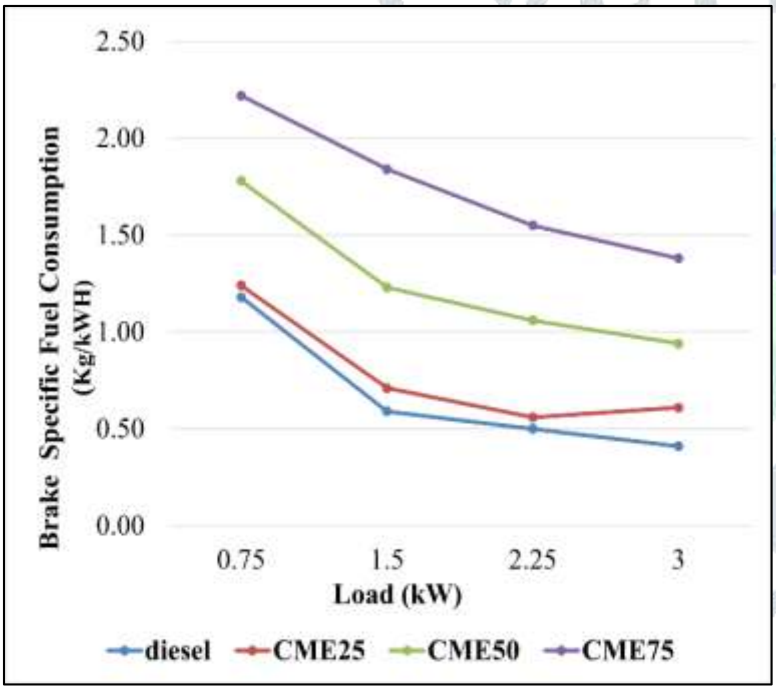

Figure.5 Brake Specific Fuel Consumption VS Load

a) BRAKE THERMAL EFFICIENCY(BTE):

Brake thermal efficiency is the evaluation of an engine's capacity to convert the Heat energy of fuel into Mechanical energy. It is also defined as the ratio of the brake power obtained from the engine to the fuel energy supplied to the engine.

$$BTE = \frac{Brake\ power}{fuel\ Power}$$

Brake Thermal Efficiency is compared for the different blends of biodiesel and shown in Figure.4

From the Graph plotted in Figure.4, it is seen that as the load increases the Brake Thermal Efficiency of Diesel as well As Different blends of Biodiesel goes on increases.

The Brake thermal Efficiency also increases as we decrease the concentration of biodiesel Which means that the Higher blends of Biodiesel have lower Brake thermal Efficiency at the Constant load.

By considering diesel as 100% at full load conditions, CIME25 shows a 79.95% deviation, CIME50 shows a 69.23% deviation and CIME75 shows a 53.82% deviation.

b) BRAKE-SPECIFIC FUEL CONSUMPTION:

Brake-specific fuel consumption (BSFC) is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational, or shaft power.

It is the rate of fuel consumption divided by the power produced.

$$BSFC = \frac{Fuel\ Consumption\ Rate}{Power\ produced}$$

In traditional units, it measures fuel consumption in pounds per hour divided by the brake horsepower, lb/(hp·h); in SI units, this corresponds to the inverse of the units of specific energy, kg/J = s^2/m^2

The observations are plotted as Brake specific fuel consumption vs Load shown in the figure.5. From the graph it is clear that at 25% load, the Brake Specific Fuel Consumption is High and goes on decreasing as we increase the load. For the higher blends of biodiesel, the Brake specific fuel consumption is high than the lower blends.

By considering diesel as 100% at full load conditions, CIME75 shows 3.4 times more BSFC, CIME50 shows 2.3 times more BSFC and CIME25 shows 1.5 times more BSFC. Hence We can conclude that the CIME blends have more Brake Specific Fuel Consumption than the Diesel.

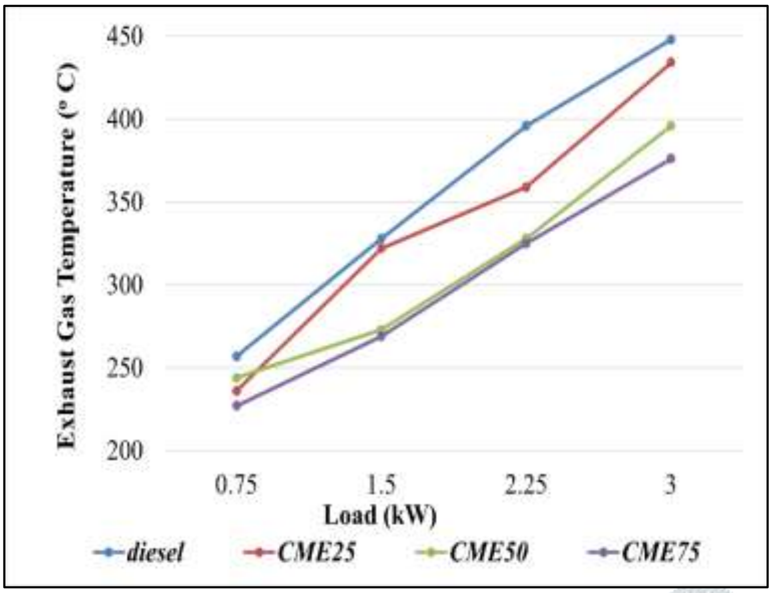

Figure.6 Exhaust Gas Temperature(^{0}C) VS Load

c) **EXHAUST GAS TEMPERATURE:**

Exhaust gas temperature (EGT) may be the most critical operating parameter on your diesel engine, because excessive EGT can bring a host of problems that fall under the meltdown category, both figuratively and literally. Every material has a melting point, some lower than others, and when things get too hot, expensive parts within or attached to your engine start welding themselves together or disintegrating into the exhaust pipe.

In Figure.6 the variation in Exhaust gas temperature of diesel as well as different blends are shown. Diesel engine exhaust gas temperature varies with speed and load. High loads and high speeds result in the highest temperatures. The Exhaust Gas Temperature for the Higher blends is low as compared to diesel and other low blends.

By considering diesel as 100% at full load conditions, CIME25 shows a 96.87% deviation, CIME50 shows an 88.39% deviation and CIME75 shows an 83.93% deviation from diesel. Hence At Full load, CIME75 has a lower exhaust gas temperature.

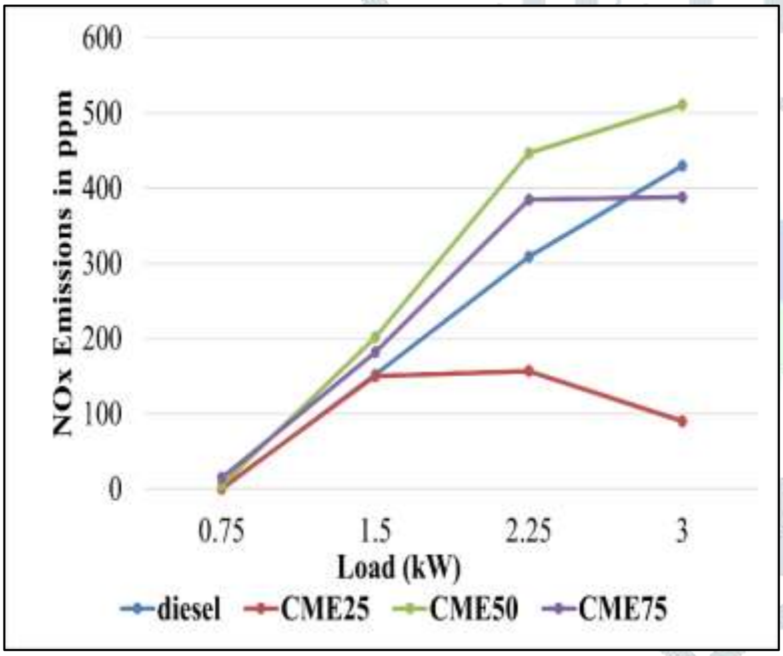

Figure.7 NOx Emission(ppm) VS Load

d) **NOX EMISSION:**

The Variation of Nitrogen oxides for Diesel and different blends of Biodiesel is plotted as a graph in the Figure.7 Among the air pollutants gasoline and diesel engines emit are oxides of nitrogen. NO, and NO2, generically abbreviated as NOx. Nitrogen oxides have harmful direct effects on human health and indirect effects through the damage they do to crops and ecosystems.

From the graph, it is shown that the NOx emission for the CIME25 has less emission than the diesel and all other blends when operated at a load greater than 50%. Generally, NOx emission for all the blends goes on increasing as the blend ratio goes on increasing except CIME25.

By considering diesel as 100% at full load conditions, CIME25 shows a 20.93% deviation, CIME50 shows a 118.84% deviation and CIME75 shows a 90.23% deviation from diesel. Hence At Full load, CIME25 has a lower NOx emission.

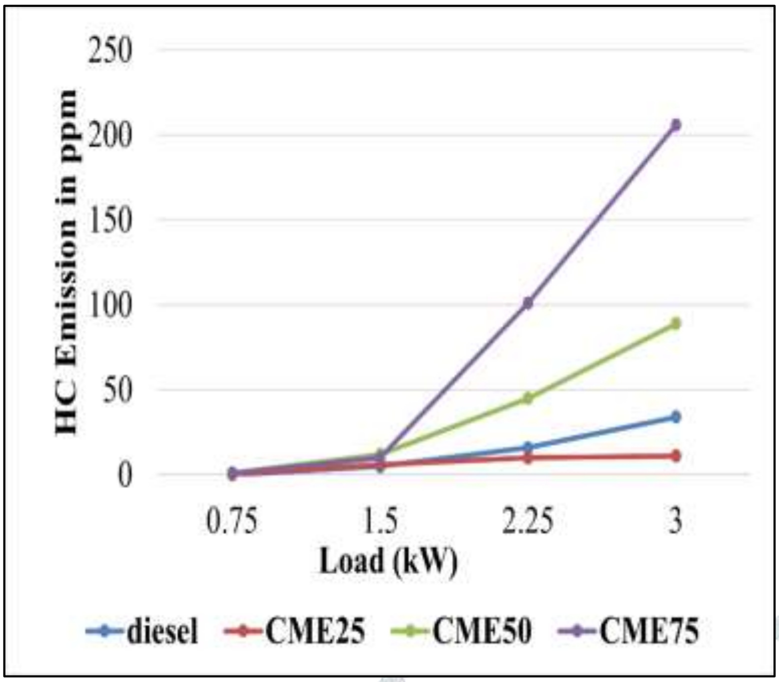

Figure.8 HC Emission(ppm) VS Load

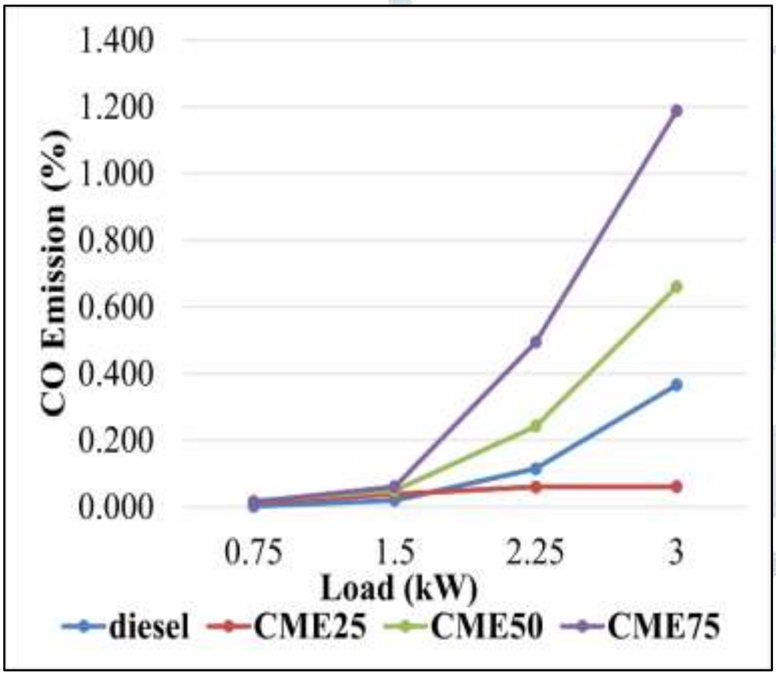

Figure.9 CO Emission(ppm) VS Load

e) HC EMISSION:

Various emissions such as HC, CO, NOx, and smoke values are obtained for the diesel and CIME blends. The incomplete combustion of fuel is one of the main reasons behind the occurrence of hydrocarbon emissions.

The combustion in diesel engines is very complex due to its heterogeneous nature, where fuel evaporation, fuel-air and burned-unburned gas mixing, and combustion occur simultaneously. Consequently, many processes could contribute to diesel engine hydrocarbon emissions.

The HC emission for diesel and CIME blends are shown in Figure.8. Emissions of Hydrocarbon for diesel as well as CIME blends go on increasing as load increases. But for the CIME25 the emission after 50% load is not increased as happens in the other cases. Also, it is low as compared to diesel at loads greater than 50%

By considering diesel as 100% at full load conditions, CIME25 shows a 32.35% deviation, CIME50 shows a 261.77% deviation and CIME75 shows a 605.88% deviation from diesel. Hence At Full load, CIME25 has a lower HC emission whereas CIME75 has more than 6 times the emission than the diesel.

f) CO EMISSION:

Carbon monoxide is one of the highly toxic gas and the main reason for the formation of CO is the partial oxidation of compounds containing carbon. CO plays a major role in the formation of ground-level ozone.

The variation in the Emission of Carbon Monoxides for Diesel as well as Different Blends of CIME at various Loads is shown in Figure.9.

The Carbon Monoxide emission goes on increasing as we increase the Loads. Also, the Emissions go increasing from diesel to higher blends of the CIME. For CIME25 the emission of Carbon monoxide is Comparatively lower than the Diesel at loads greater than 50%. The CO emission follows the same trend as the HC emission. The CO emission decreases with an increase in the percentage of biodiesel in the blends.

By considering diesel as 100% at full load conditions, CIME25 shows a 16.67% deviation, CIME50 shows a 180.6% deviation and CIME75 shows a 324.59% deviation from diesel. Hence At Full load, CIME25 has a lower CO emission whereas CIME75 has more than 3 times the emission than diesel.

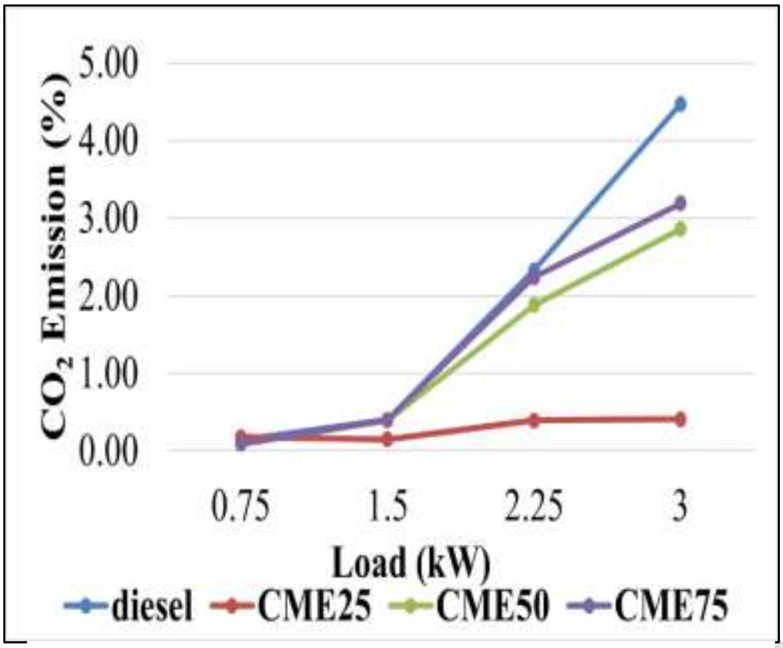

Figure.9 CO_2 Emission(ppm) VS Load

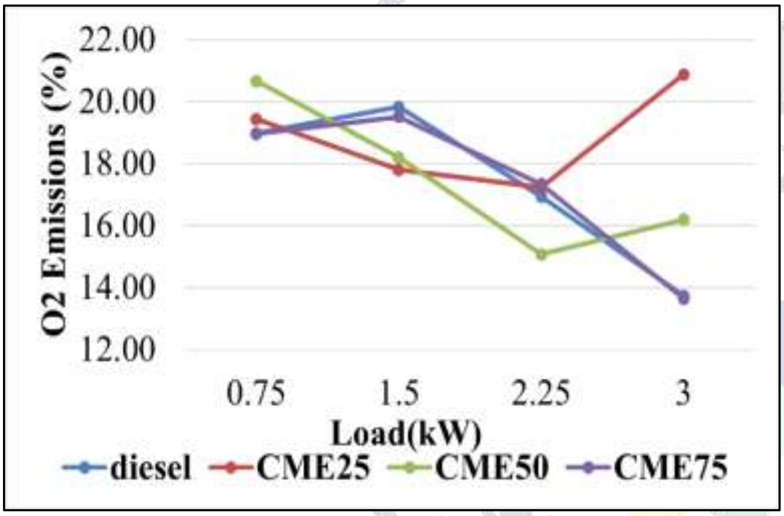

Figure.10 O_2 Emission(ppm) VS Load

g) CO_2 Emission

Carbon Dioxide is one of the highly toxic gases and the main reason for the formation of CO_2 is the partial oxidation of compounds containing carbon and carbon Monoxides. Carbon Dioxide plays a major role in the pollution as well as global warming.

The variation of the Carbon Dioxide for diesel and Different blends of CIME is shown in Figure.10. From the graph it is clear that the emission of the CIME blends is lower than the Diesel.

Also, the percentage emission of Carbon Dioxide for the CIME25 blend is less than the CIME50 and CIME75. CIME25 shows less percentage of emissions than the other two.

Based on the load as the load increases the percentage emission of carbon dioxide also increases.

By considering diesel as 100% at full load conditions, CIME25 shows a 9.17% deviation, CIME50 shows a 63.98% deviation and CIME75 shows a 71.37% deviation from diesel. Hence At Full load, CIME25 has a lower CO_2 emission.

h) O2 Emission

The variation of the Oxygen for diesel and Different blends of CIME is shown in Figure.11. From the Graph it is seen that the oxygen emission is almost the same for diesel and CIME75. As the Load increases the Oxygen Emission for the Diesel and CIME75 decreases.

Whereas Oxygen emission for the CIME25 and CIME50 decreases up to 75% load and then Increases drastically.

By considering diesel as 100% at full load conditions, CIME25 shows a 152% deviation, CIME50 shows a 117.92% deviation and CIME75 shows a 99.42% deviation from diesel. Hence At Full load, CIME75 has almost equal emissions to diesel.

VI. Conclusion

Calophyllum Inophyllum methyl ester oil obtained from the feedstock is converted into biodiesel. Then biodiesel is blended with diesel in the proportion of CIME25, CIME50, and CIME75 for engine testing. The performance, emission, and combustion characteristics of different blends of CIME biodiesel are compared to those of the fossil fuel diesel, and the results are summarized as follows:

1. As we have seen the property of CIME is in Table.1 Most of the properties of CIME biodiesel are similar to diesel fuel. Due to this, it can be concluded that the blends of CIME can be used without any modifications in the diesel engine.
2. It is seen that as the load increases the Brake Thermal Efficiency of Diesel as well As Different blends of Biodiesel goes on increases.
3. Brake Specific Fuel Consumption increase with the increase in the percentage of CIME biodiesel in the blends. It decreases as the load increases.
4. HC, CO, and NOx emissions go on increasing as the load increases. But for CIME25 emission is less than the diesel and other blends of CIME.
5. the percentage emission of Carbon Dioxide for the CIME25 blend is less than the CIME50 and CIME75. CIME25 shows less percentage of emissions than the other two.

From the conclusions, we can conclude that Calophyllum Inophyllum Methyl Ester can serve as a suitable alternative to conventional diesel fuel. It is more environmentally friendly in nature. As in this paper Compression Ratio is fixed due to which further studies related to various blends of biodiesel with diesel and various compression ratios can be a deciding factor in finding the optimum conditions to utilize the biodiesel in a better way.

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