Optimization of Compression Ratio in the improvement of CI Engine Characteristics fueled with methyl ester of rubber seed oil

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ABSTRACT

Direct utilization of raw rubber seed oil (RSO) as a fuel in the CI engine leads to incomplete combustion owing to improper injection and atomization of fuel which affects the thermal efficiency and leads to higher emission. Pertaining to this issue, the density and viscosity of the fuel are lessened and the properties of fuel are amended to that of diesel by converting the raw rubber seed oil into its methyl ester through the process called transesterification. The design of experiment is used to find the optimum process parameters to increase the biodiesel yield. The compression ratio in a four stroke single cylinder is varied from 16 to 22 for different fuel blends at full load conditions and at a constant speed to make a comparative study. Based on the experimental analysis, blend B25 gives the maximum thermal efficiency of 32.15% for CR20. The emissions at full load conditions for CO, HC & NOx were noted as 0.83%, 30.4ppm & 223ppm and it is collated with that of diesel fuel. Finally it is concluded that CR20 gives the optimum performance and emission characteristics for the blend B25. Therefore rubber seed oil based methyl ester (RSOME) can be used as a penurious fuel even in an unmodified diesel engine.

Key words: *Rubber seed oil, Biodiesel, Emission, Engine performance, Compression ratio*

INTRODUCTION

The demand of petroleum products over the globe made the investigators to find an alternative source of energy for the petroleum based fuels. Increase in the number of vehicles in automobile sectors requires more need for fossil fuels, but on the other hand fossil fuels are

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deteriorating endlessly, so it is indispensable to find a proxy for the fossil fuels. The environment gets polluted by using diesel fuel in automobile sectors, which can be reduced by bio fuels. Biofuels are available in plenty in nature, in which biodiesel takes up the most essential role due to its inevitable properties like presence of oxygen, non-hazardous, ecofriendly and biodegradable. Predominantly enormous researches on biofuel are still done by creating an awareness to prevent the entire globe from global warming. Though biofuel has similar properties of diesel fuel, few other properties such as flash point, viscosity and heating value are slightly dissimilar than the diesel fuel, which should be analyzed before getting into the process of combustion in diesel engines **[1].**

Biofuels can be extracted from both non-edible and edible oils, but usage of edible oil in India is not feasible, since it is highly used for cooking purpose. However Vegetable oils are eco friendly to environment, since they do not contain any aromatic compounds. Enormous researches have been done in combustion engines from its way back so it is not conceptualization of the present **[2].** Because of its enhancing property like low emission in engine exhaust during combustion, Biodiesel can be replaced in diesel engines. However very few biofuels generate more oxides of nitrogen than diesel fuel which leads to ozone depletion. Normally oxides of nitrogen in a larger amount is represented due to high temperature generated in engine exhaust **[3].** This type of minor errors can be rectified by using some additives that can be blended with the fuel while it is used in engines. Thermal efficiency of an engine can be improved by reducing the emission during the combustion process **[4].** Several researchers have found out that pure biodiesel emits reduced particulate matter and smoke due to its higher oxygen content. To analyze the effect of oxygen content in the exhaust, different types of oxygenated fuels such as esters, alcohols, ethers are experimented in engines **[5,6].**

MATERIALS AND METHODS

Extraction of Rubber seed oil

Hevea brasiliens the natural rubber belonging to Euphorbiaceae family is grown in tropical humid conditions. The latex that oozes when the bark of the tree is cut comprises about 30% rubber, which can be solidified and treated into solid products, such as vehicle tyres. Over the globe India takes up the seventh place in producing rubber. Hefty amount of rubber plantation is found in the state of Kerala (Fig. 1). Around 2.75 lakhs hectare is utilized for rubber plantation in India which yields an average of 165 kg of rubber seeds per hectare. The rubber

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seeds are having ellipsoidal shape, brown in colour ranging from 25-28mm long and weighing 3-5gm each. The rubber seeds possess oil content around 40-60 wt.% **[7].** From the collected rubber seeds the kernels are segregated, dried to take away the moisture content and the oil is extracted by a pressing operation using a mechanical device. The collected oil is filtered and further it is utilized for biodiesel extraction. The rubber cakes that are left over after the extraction of oil can be used as a feedstock for pigs & poultry due to its high nutritional value.

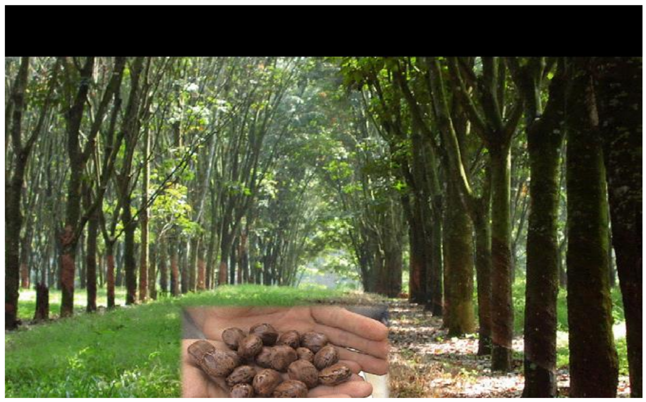

Fig. 1 Photograph of rubber plantation along with rubber seed

Biodiesel Extraction and its Process Optimization

The oil extracted from the rubber seed has a high viscosity, with acid value of 34mg/KOH/g corresponding to 17% of free fatty acid content. The direct usage of oil hampers the engine due to its high viscous nature. To overcome this, by reducing the viscosity of the oil, a two stage transesterification process is opted for extracting biodiesel from the raw oil **[8].** The first stage focuses on acid esterification to minimize the acid number of raw oil from 34 to 3mg/KOH/g. The major intention of the second stage is to increase the biodiesel yield during alkaline esterification by undergoing chemical reaction with alcohol in the presence of a base catalyst by the conversion of triglycerides into monoesters. An optimization technique using design of experiment (DOE) is used to analyse the relationship between the input process parameters and the response parameters and to optimize the reaction conditions using design experts software. The major process parameters used for the multi-variant approach to optimize the yield are oil/methanol ratio, temperature, time, and volume percentages of catalyst.

Physico-chemical and Gas Chromatography analysis

The extracted biodiesel's physico-chemical characteristics were assessed using established testing procedures. A LV-DV-II+ BROOKFIELD At 40°C, a pro viscometer is utilized to quantify the viscosity. The fire and flash points are measured using Pensky Martins closed cup apparatus. The energy content of the biodiesel was measured utilizing a standard 6772 calorimetric thermometer. The fatty ester content was determined using a GC 2010 gas chromatograph Shimadzu, which was calibrated according to EN 14103, version 2003 **[9]**.

Performance and emission analysis on VCR engine

To undergo an experimental analysis by using RSOME as input fuel in the engine, a VCR single cylinder diesel engine is selected to analyze various engine characteristics. A data acquisition system is connected with the setup in which during the combustion time sensors attached within the engine can give the output result by using the engine software installed in the system. Fig. 2 shows the photographic view of the VCR engine. The engine is connected with an eddy current dynamometer for loading in steps and to measure the engine output power. The cylinder pressure inside the engine is measured by using a piezo electric transducer coupled with it. The signals received from the cylinder is paused to the engine software through data acquisition system which gives the results such as heat release rate, ignition delay and pressure rise.

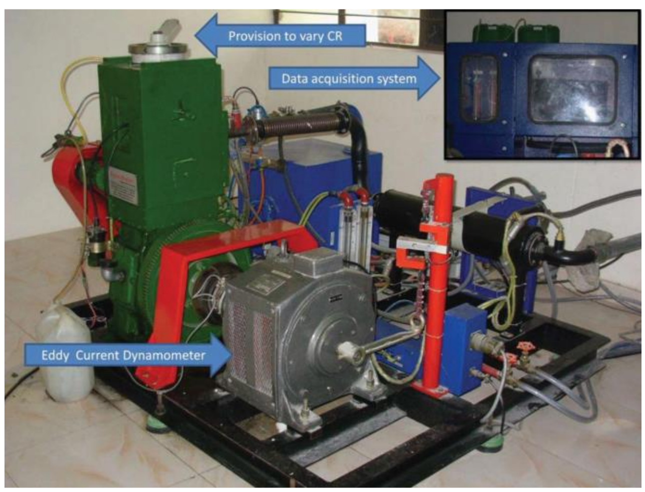

Fig.2 Variable Compression Ratio Diesel Engine

Compression ratio (CR) plays a vital role in diesel engine to optimize the combustion as well as emission parameters. Clearance volume is varied by moving the cylinder head up and down with the help of a rotating arm and thereby CR can be varied . To carry out the emission analysis, a portable multi gas analyzer named Quintox is used, which gives the result of various composition of gases such as nitric oxide, carbon monoxide, carbon dioxide, hydrocarbon, etc.

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RESULTS AND DISCUSSION

Transesterification Process Optimization

Analysis of Variance (ANOVA) was used to check the experimental model of RSOME production for suitability and significance. The Signal-to-Noise Ratio (SNR) values were estimated to be 99.47, and the p-value for the model was lesser than 0.0001, indicating that the model is suitable. The optimum yield for RSOME is found out, when NaOH is at a lower level of 0.5%w/v and the methanol to oil ratio is all over 0.2% v/v. The three dimensional graph for the alkaline esterification achieved by using design expert software is illustrated in Fig. 3. The elaborative optimization analysis using DOE for acid and alkaline esterification has been already published **[8].**

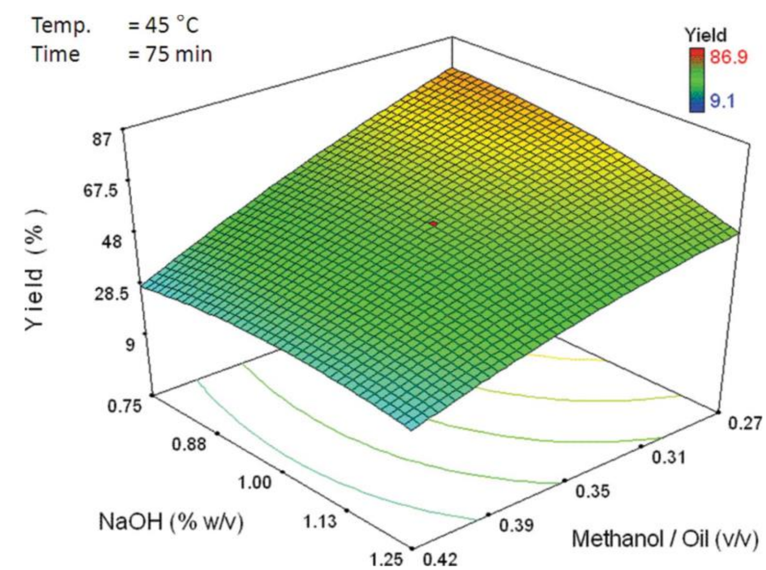

Fig. 3 Graphical form of biodiesel yield by alkaline esterification

Physico-chemical and Gas Chromatography Analysis

The qualities of RSOME were confirmed to be within various biodiesel standards (Table 1). The immediate utilization of RSOME as a fuel in a CI engine is limited due to higher fuel property values. Transesterification of RSO into RSOME reduced kinematic viscosity to within acceptable limits **[9]**. Due to diesel fuel's strong temperature characteristics, which often rises at lower temperatures, running engines in areas with cold climates are challenging. The low-temperature fuel flow characteristics must therefore be carefully examined using the Cold Filter Plugging Point (CFPP). The CFPP is the lowest temperature at which biodiesel passes through a wire mesh filter screen in a vacuum for a period of 60 seconds. For safe handling and storage,

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other physico-chemical characteristics like flashpoint, fire point, cetane number, and oxidation stability are within acceptable bounds **[7]**. It was discovered that there were more unsaturated fatty acids than saturated ones (96.96%), which supports earlier studies and suggests that RSOME will have a somewhat higher viscosity and a lower calorific value **[9].** Gas chromatography studies clearly demonstrated a larger potential for converting rubber seed oil feedstock with lower energy densities into bio-oils with higher energy densities.

Table 1 Properties of RSO, RSOME & Diesel

Properties	Unit	Test Procedure	RSO	RSOME	Diesel	Biodiesel Standards		
						BIS India	ASTM D6751	EN 14214:2012
Kinematic Viscosity@40°C	cSt	ASTM D445	30	3.92	3.18	3.5–5	1.9–6	3.5-5.0
Cetane Number	-	ASTM D4737	49.73	51.06	45	51	47 min	51 min
Flash Point	°C	ASTM D93	243	128	65.5	100	130	101
Density@15°C	kg/m³	ASTM D792	910	860	830	860-900	880	860-900
Fire Point	°C	ASTM D92	254	109	70.5	-	106-180	-
Calorific Value	MJ/kg	ASTM D240	39.34	38.2	44.99	-	35 min	-
Oxidation Stability@110°C	Hrs	ASTM D942	-	7.5	-	-	3 min	8 min
Cold Filter Plugging Point	°C	ASTM D6371	-	-0.62	-5	-	+5 max	+5/-20

Performance Analysis

Brake Thermal Efficiency (BTE)

The change in BTE for diesel and its blends when the engine is running under varying CRs from 16 to 22 is shown in Fig 4. From the graph it is revealed that increase in CR increases the engine efficiency to an extent and further increase decreases the efficiency. The maximum value of BTE achieved for CR20 for diesel, B25, B50, B75 & B100 are 29.76%, 32.15%, 30.35%, 28.23% and 26.48% respectively. When RSOME is blended with diesel fuel to an extent of twenty five percent, a complete combustion is noticed attributable to the atomization

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and inter-mixture of fuel particles with air which leads to higher brake thermal efficiency at peak loads **[10]**.

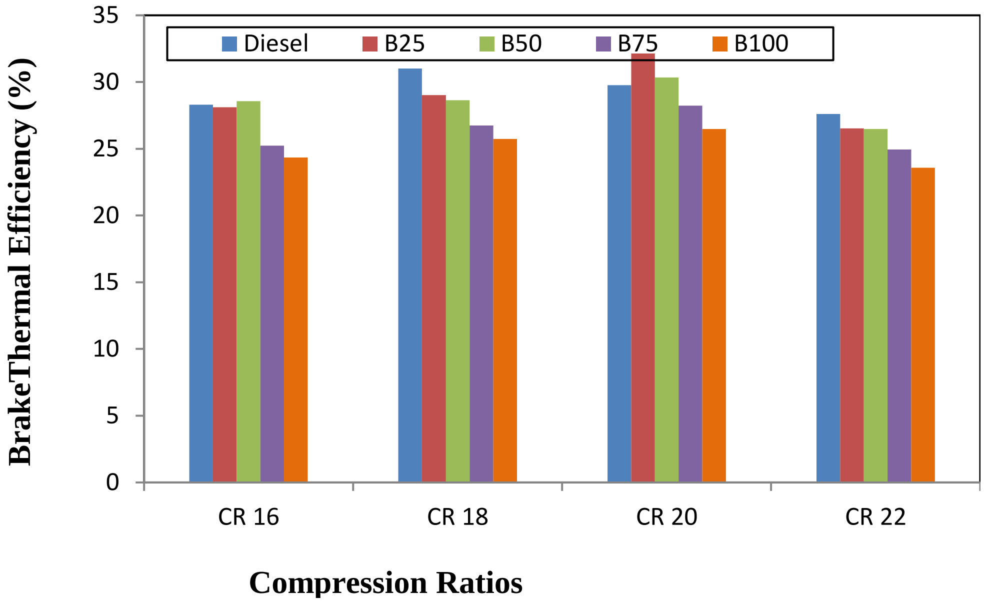

Fig.4 Change in BTE at varying CRs for different RSOME blends and diesel

Specific Fuel Consumption(SFC)

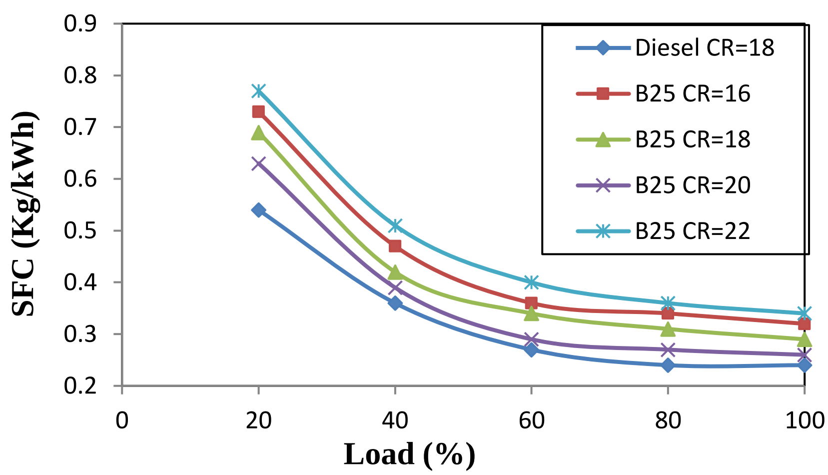

Fig. 5 Change in SFC with load for B25 and Diesel at varying CRs

Specific fuel consumption mainly deals with the intake of fuel by the engine to generate the out put. Normally SFC decreases with addition in load due to more consumption of fuel when loading is done from zero to 100%. Fig. 5 shows the change in SFC for the blend B25 & diesel fuel when running under various CRs. It is noticed that the SFC is lower for diesel fuel than B25, even though increase in efficiency was noticed for B25 at CR20 **[11,12].** The maximum SFC is noted for CR 22 at full load condition is 0.34Kg/KWh, due to its incomplete combustion.

Combustion Analysis

Cylinder Peak Pressure

The need to study the cylinder pressure is to analyze the effectiveness of combustion carried out inside the engine cylinder. Fig. 6 depicts out the change in cylinder peak pressure with increasing load for B25 & diesel under different CRs. The cylinder pressure increases with increase in load and it depends mainly on the evaporation of fuel during the ignition delay period. When running under the standard compression ratio, the maximum cylinder peak pressure is achieved for diesel, owing to its complete combustion and improved atomization of fuel which generates maximum power output at full load conditions. For the compression ratio of 22, very low cylinder pressure is noticed due to more fuel consumption during the suction stroke, in which the ignition delay is more as compression ratio goes higher [**13]**.

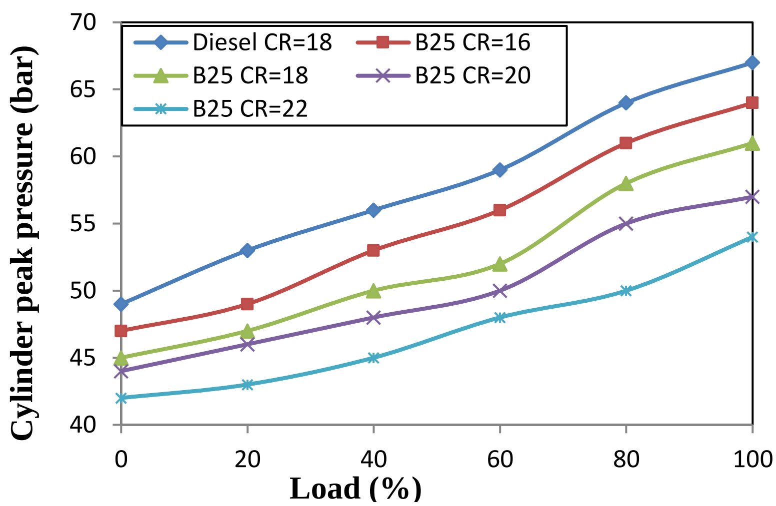

Fig. 6 Change in Cylinder peak pressure with load for B25 and Diesel at varying CRs

Combustion Duration

The duration of combustion for different CRs is analysed for the blend B25 along with the diesel fuel. Fig. 7 shows the change in combustion duration for B25 biodiesel blend and diesel at varying CRs. Several studies have revealed that the time taken by the engine to undergo complete combustion is more due to its poor volatility for the higher viscous fuels. There is a delay in fuel injection due to increase in density of fuel. It is obvious that increase in load increases the duration of combustion by the absorption of fuel to a greater extent inside the

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combustion chamber, similar to that increase in CR also increases the duration of combustion [**14**].

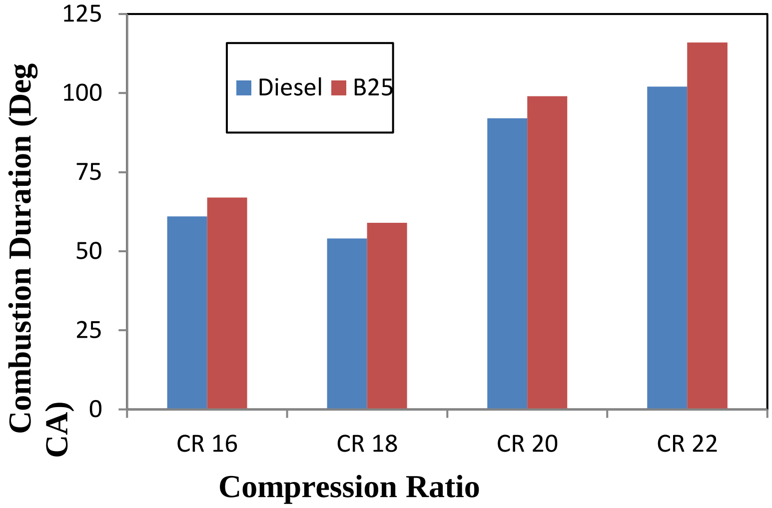

Fig. 7 Change in Combustion duration for B25 and Diesel at varying CRs

Emission Analysis

Exhaust Gas Temperature (EGT)

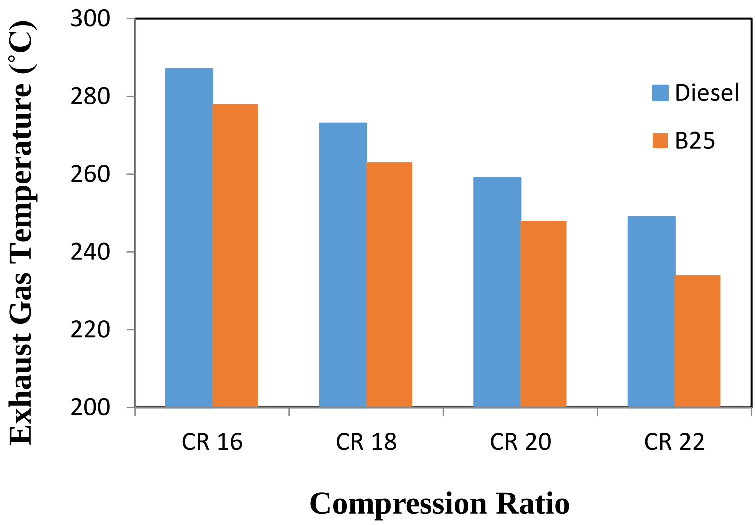

Fig. 8 Change in EGT for B25 and Diesel at varying CRs

The temperature generated inside the engine cylinder during combustion is released through the engine exhaust with the combination of smoke, which is measured by the temperature analyzer. Fig. 8 shows the change in EGT for B25 and diesel for different CRs. It is also noted that when the load is increased the exhaust gas temperature of the engine also increases for the biodiesel blends and diesel fuel. When comparing the temperature of both the

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fuels, maximum generation of temperature is noticed for diesel fuel. On the other hand, increase in CR decreases the exhaust gas temperature for both the fuels, the reason behind is during the suction stroke, atmospheric air is sucked and compressed to high air temperature which undergoes complete combustion and minimizes the temperature at the engine exhaust [**15,16**]. The maximum and minimum temperature recorded for diesel is 287ºC for CR16 and 249ºC for CR22, similarly for B25 the attained values are 278ºC for CR16 and 234ºC for CR22.

Carbon Monoxide (CO) emission

Generally diesel engines undergo combustion process by consuming lean mixture of air fuel ratio, so normally CO emission is minimum [**17**]. Fig. 9 shows the change in CO emission with different CRs for diesel and B25 biodiesel blend at full load conditions. From the graph it clearly emphasizes that when the CR is increased for 16 to 22 the CO emission decreases gradually for both diesel and biodiesel blend. However, lower CO emissions are noted for the blend B25 than diesel fuel due to the concentration of oxygen which initiates a complete combustion [**18**]. When the diesel engine undergoes combustion with biodiesel, lower CO emission is noticed, which will be helpful in minimizing global warming. The CO emissions found for different CRs for the blend B25 are 1.15, 0.88, 0.73 and 0.62% respectively which is around 12 to 16 percentage reduction in comparison with diesel fuel.

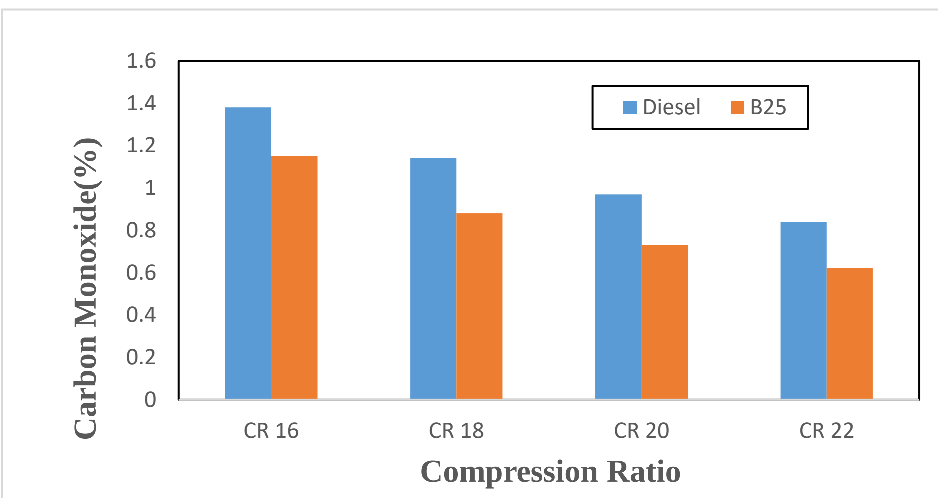

Fig. 9 Change in CO emission for B25 and Diesel at varying CRs

Hydro Carbon (HC) emission

Normally in diesel engines, hydrocarbon emissions are higher due to the incomplete combustion inside the engine cylinder. The major parameters which affects the hydrocarbon emissions are composition of fuel, injection timing and pressure, fuel spray characteristics,

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loading of the engine, design parameters of combustion chamber and its speed [**19]**. The change in hydro carbon emission for B25 and diesel fuel for different CRs is shown in Fig. 10. By analyzing the graph, the HC emission is found to be lower for the blend B25 at CR20 when compared with the other compression ratios, owing to the oxygen concentration in the biodiesel blend. The temperature and pressure gets increased inside the engine cylinder which undergoes complete combustion which leads to reduction in hydrocarbon emission. The recorded values of HC emission for the blend B25 for compression ratios of 16,18,20 and 22 are 32.5ppm, 37.6ppm, 30.4ppm and 32.3ppm. The HC emission for diesel fuel is more for all CRs in comparison with the B25 blend due to its lean mixture and deficiency in oxygen concentration.

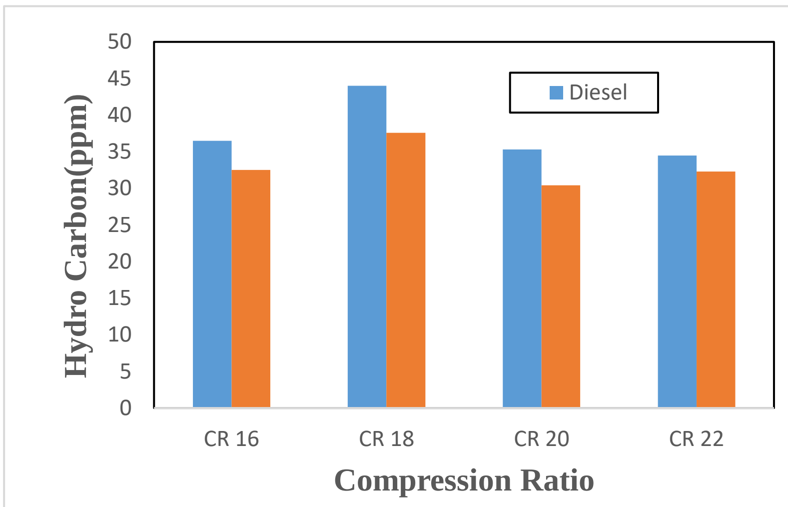

Fig. 10 Change in HC emission for B25 and Diesel at varying CRs

Nitric Oxide (NOx) emission

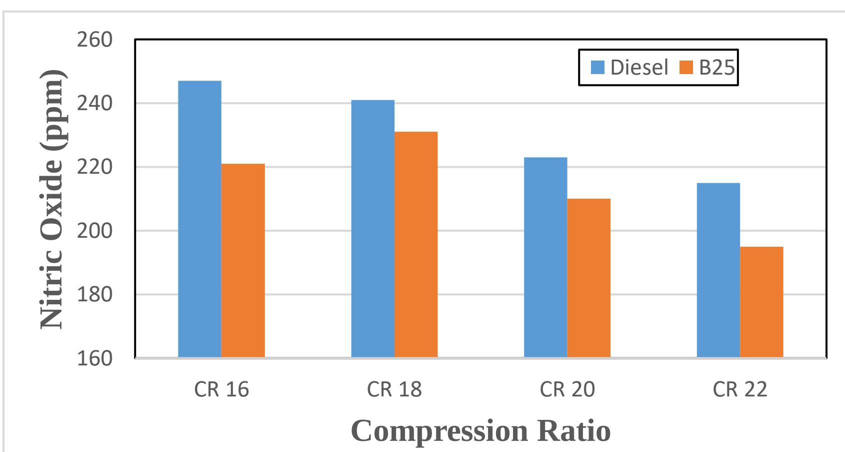

Fig. 11 Change in NOx emission for B25 and diesel at varying CRs

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During the combustion, the temperature inside the engine cylinder increases with respect to the flame temperature. The generation of nitric oxide emission mainly depends on the oxygen content. During suction stroke, atmospheric air is sucked inside the engine cylinder, in which oxygen is the major supporter for combustion which reacts with nitrogen and leads to the generation of NOx emission **[20]**. The change in Nitric Oxide emission for B25 and diesel for varying CRs is depicted in Fig. 11. NOx emission mainly depends on the exhaust gas temperature during combustion. It can be analyzed from the graph that nitric oxide emissions are higher for diesel fuels when compared with blend B25, on the other hand increase in compression ratio decreases NOx emission for both diesel and B25 **[21].** Normally nitric oxide emission was decreased on an average of 3% when the CR is increased from 16 to 22. The NOx emission for B25 fuel decreased from 221ppm to 195 ppm, similarly for diesel the maximum and minimum values of NOx emission are recorded as 247ppm at CR of 16 and 215ppm at CR of 22 respectively.

CONCLUSION

Rubber seed oil cannot be utilized directly as a fuel in CI engines due to its high viscosity and FFA content. To overcome this, two stage transesterification process is carried out to reduce its viscosity and an optimization technique using 'design of experiment' is utilized as a tool to increase the biodiesel yield. The extracted biodiesel when analysed for fuel properties was found to be similar to the properties of diesel fuel.

A four stroke, single cylinder variable compression ratio diesel engine is utilized to analyze the various engine characteristics. Initially the performance test was carried out for different blends for different CRs and it is optimized that B25 blend shows better performance than diesel fuel. RSOME for the blend B25 gives the maximum thermal efficiency of 32.15% for CR 20, which is 2% higher than that of diesel. The maximum value of thermal efficiency achieved for CR20 for diesel, B25, B50, B75 & B100 are 29.76%, 32.15%, 30.35%, 28.23% and 26.48% respectively. The result clearly shows that blend B25 attains the maximum efficiency for CR20 than any other blends.

When the RSOME is blended with diesel fuel to an extent of twenty five percentage a complete combustion is noticed owing to the proper atomization and mixing of fuel particles with air that lead to higher brake thermal efficiency at peak loads. Reduction in emissions can be noticed for CO, HC and NOx for the blend B25 than the diesel attributed to its oxygen content which affirms the utilization of RSOME as a viable substitute to diesel.

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