



# Experimental Investigation of Performance and Emission Characteristics of Calophyllum Inophyllum Oil Biodiesel on VCR-Diesel Engine

<sup>#1</sup>Nilima Baliram Gadge, <sup>#2</sup>Dr. Abhay A. Pawar

<sup>1</sup>nilimagadge80@gmail.com

<sup>2</sup>pawar\_abhay@rediffmail.com

<sup>#1</sup>PG Student Mechanical Engg Department, Pune University  
JSPM's Rajarshi Shahu College of Engineering, Tathawade, Pune, India.

<sup>#2</sup>Guide, Mechanical Engg. Department, Pune University  
JSPM's Rajarshi Shahu College of Engineering, Tathawade, Pune, India

## ABSTRACT

An increasing demand of fossil fuels has being a critical problem for us. The natural resources of fossil fuel are dwindling day by day. Biodiesel that may call natural fuel could be a good source or substitute for fossil fuel in future. Biodiesel can be produced from non edible oil like *Jatropha curcus*, *Pongamia pinnata*, *Madhuca indica*, *Gossypium arboreum*, *Simarouba glauca*, Palm, Coconut, Soyabeen etc. and more. There is a best source as a raw material that is *Calophyllum Inophyllum* oil for biodiesel production. As it has second highest productivity of 5000 litres per hectare and an evergreen tree and grows along the coastal area. And the study is focused on finding alternative fuel to diesel engine without any engine modification. This paper reviews the preparation of biodiesel from *Calophyllum Inophyllum* oil by transesterification, and an experiment is conducted to obtain the operating and emission characteristics of *Calophyllum Inophyllum* oil biodiesel on variable compression ratio (VCR) engine run on various blends of biodiesel, compression ratios and load conditions. From the comparison of results and doing validation with Buckingham's  $\pi$  Theorem Analysis and Regression Equations, it is inferred that the engine performance is improved with significant reduction in emissions for the chosen oils without any engine modification. The effective compression ratio and blend on the basis of the experimental results obtained is 16.5 and H25 respectively, since the findings of the present research work infer that the biodiesel obtained from *Calophyllum Inophyllum* oil is a promising alternative fuel for direct-injection four-stroke VCR diesel engine.

**Keywords—** Biodiesel, *Calophyllum Inophyllum* Oil, Transesterification, VCR Diesel Engine, Performance & Emissions, Compression Ratio, Blend, Engine Load .

## ARTICLE INFO

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## I. INTRODUCTION

The fast depletion of world's petroleum reserves and increasing ecological concerns has created a great demand for environmentally benign renewable energy resources. Biodiesel has emerged as a sustainable alternative to

petroleum origin diesel and its usage have been encouraged by many countries.

Diesel engines provide important fuel economy and durability advantages for large heavy-duty trucks, buses, and non road equipment and passenger cars. They are often the power plant of choice for heavy-duty applications.

While they have many advantages, they also have the disadvantage of emitting significant amounts of particulate matter (PM) and oxides of nitrogen (NO<sub>x</sub>) and, to a lesser amount, hydrocarbon (HC), carbon monoxide (CO), and toxic air pollutants.

Biodiesel is attractive as an alternative fuel source because its emissions profile is cleaner than that of diesel fuel. Biodiesel can be used in diesel engines without modification, and can be blended with petrol-diesel fuel effectively. A blend of 20% biodiesel and 80% diesel fuel, is currently the most widely used form of biodiesel.

Calophyllum Inophyllum Oil chosen for the present work of experimental investigation of performance and emission characteristic on VCE diesel engine. Calophyllum Inophyllum is a species of family Guttifereae (Clusiaceae), native to India, East Africa, Southeast Asia, Australia and South Pacific. Commonly it is called as In-dian laurel<sup>1</sup>, Alexandrian Laurel, Beach calophyllum, Beauty leaf, Pannay tree, Sweet Scented Calophyllum (in English), Pongnyet, Burmese, Hawaii, Kokani, Nagachampa, (in Mara-thi), Sultan Champa, Surpan (in Hindi), Nagam, Pinmai, Punnagam, Punnai, Pinnay, Namere (in Tamil).

The main objective of present work is to analyse the engine performance and emission characteristics of diesel engines fuelled with biodiesel produced from Calophyllum Inophyllum Oil and/or its blends with diesel fuel, which will help in both the direction of reducing emission problems and search of alternative fuel for CI engines.

## II. MATERIAL AND METHOD

The first stage (acid catalyzed) of the process is to reduce the free fatty acids (FFA) content in oil by esterification with methanol (99% pure) and acid catalyst sulfuric acid (98% pure) in one hour time at 57°C in a closed reactor vessel. The oil is first heated to 50°C then 0.7% (by wt. of oil) sulfuric acid is to be added to oil and methyl alcohol about 1:6 molar ratio (by molar mass of oil) is added. Methyl alcohol is added in excess amount to speed up the reaction. This reaction was proceeding with stirring at 650 rpm and temperature was controlled at 55-57°C for 90 min. The fatty ester is separated after natural cooling.

At second level, the separated oil from the separating funnel has to undergo transesterification. Methoxide (methanol + sodium hydroxide) is added with the above ester and heated to 65°C. The same temperature is maintained for 2 hr. with continuous stirring, and then, it undergoes natural cooling for 8 hr. Glycerol will deposit at the bottom of the flask, and it is separated out by a separating funnel. The remnants in the flask are the esterified vegetable oil (biodiesel).

## III. METHODOLOGY

As per the present authors' knowledge the use of blends of Calophyllum Inophyllum Methyl Ester – CIME in diesel engine at full load conditions and blend proportion, by varying compression ratio are not reported in the literature. The objective of the present work is to study through experiments on the performance and emission characteristics of CIME blends in direct injection (DI) diesel engine at various compression ratio.

TABLE I  
EXPERIMENTATION METHODOLOGY

Blend Type	Description	IOP in bars	Injection Timing in °bTDC	Load in KW	CR
H00	100% Diesel	210	27	0.75	15.5
H25	25% CIME + 75% Diesel			1.50	
H50	50% CIME + 50% Diesel			2.25	16.5
H75	75% CIME + 25% Diesel			3.00	

TABLE III  
ENGINE SPECIFICATIONS

Description	Specification
Make	Rocket Engineering Model VRC-1
Bore	80 mm
Stroke	110 mm
Swept Volume	553 mm
RPM	1500
Brake Horse Power	5 HP
Compression Ratio	17.5 : 1
Fuel Oil	High Speed Diesel
Coefficient of Discharge	0.65
Water Flow Transmitter	0 to 10 lit./min.
Air Flow Transmitter	0 to 250 wc
Piezo Sensor	0 to 5000 psi with low noise cable
Software	Labview

The properties of CIME (H100) and Diesel (H00) and Calophyllum Inophyllum Oil were determined as per the methods approved by Bureau of Indian Standards.

TABLE III  
PROPERTIES OF FUEL

Parameter	Diesel (H00)	CIME (H100)	Raw Oil
Density at 15°C in gm/cc	0.835	0.8653	0.9363
Kinematic Viscosity at 40°C in cst	3.5	1.744	51.58
Calorific Value in MJ/Kg	43.00	37.18	40.27
Flash Point in °C	44	8.5	220

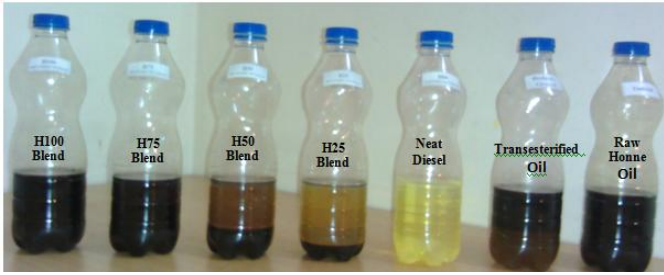


Fig. 1 Fuel sample used for experimentation

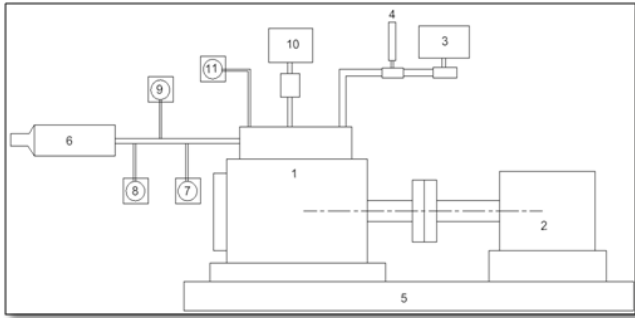
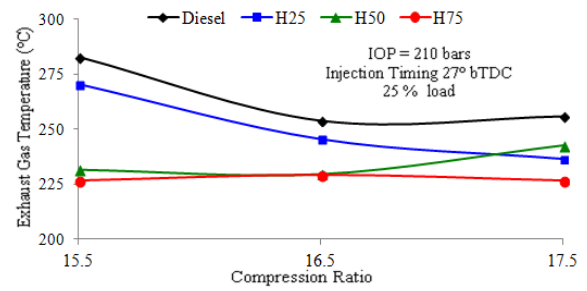
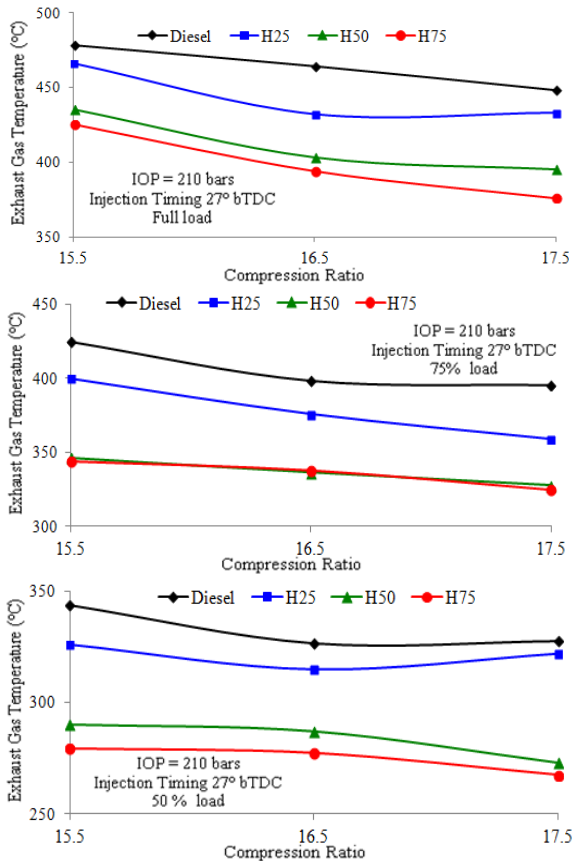


Fig. 2 Experimental Engine Setup Arrangement

- 1.- Test Engine,            2.- Eddy Current Dynamometer,
- 3.- Fuel Tank,            4.- Fuel Burette,            5.- Test Bed,
- 6.- Silencer,            7.- Smoke Meter,
- 8.- HC/CO/NO<sub>x</sub>/CO<sub>2</sub>/O<sub>2</sub> Analyzer,
- 9.- Exhaust Temperature Indicator,
- 10.- Air Flow Meter,    11.- Stop Watch

**IV. RESULT AND DISCUSSION**

**A. Variation of Exhaust Gas Temperature**



The result indicates that the variation in exhaust gas temperature is very minimal and showing the same trend at full load condition, but partial load condition upto 50% load, is distracted.

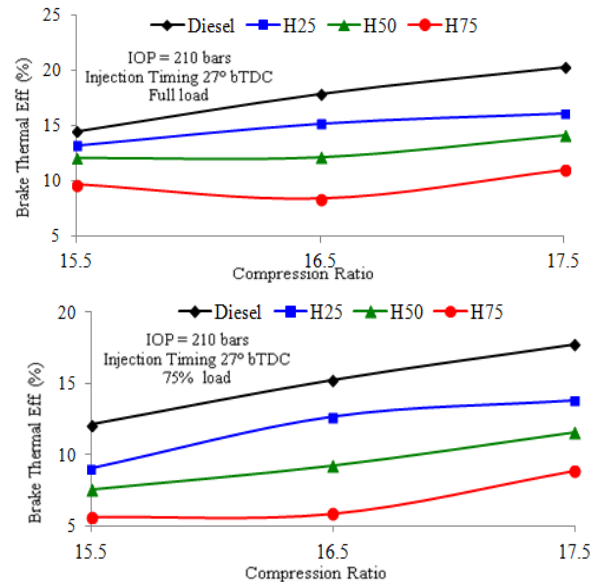
For full load condition, when the compression ratio is varied from 15.5 to 17.5, the highest temperature obtained is 478°C for diesel, 466°C for H25, 436°C for H50 and 425°C for H75, all are at the compression ratio of 15.5. The lowest temperature obtained is 448°C for diesel, 432°C for H25, 396°C for H50 and 376°C for H75, all are at the compression ratio of 17.5.

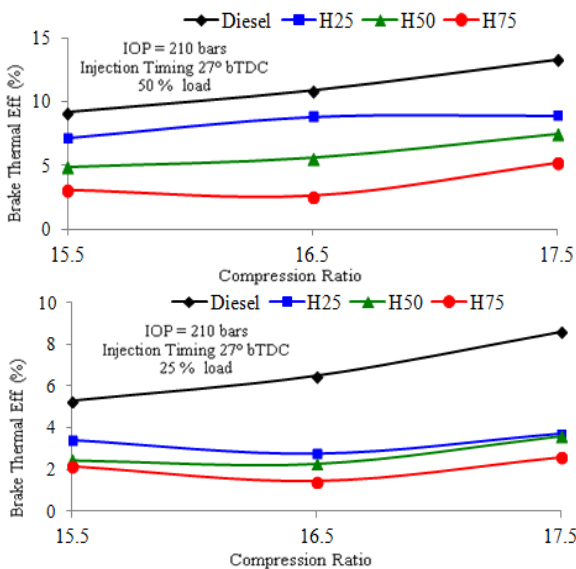
These performance characteristic curves of the biodiesel and its blends have been compared by with the diesel and found at all conditions, as shown in Figures, lower Exhaust Gas Temperature. When the load is increased, particularly at high loads. This could be due to low viscosity of biodiesel, which improve the spray injection characteristics in combustion chamber and thus leads to a less dominant diffusion combustion phase than diesel.

The multiple regression equation with three input variable, Blend, CR and Load conditions for Exhaust Gas Temperature (EGT) is,

$$EGT = 382 - 11.2 CR - 71.3 Blend + 85.6 Load$$

**B. Variation of Brake Thermal Efficiency**





It has been observed from the figures, there is a steady increase in brake thermal efficiency as compression ratio increases.

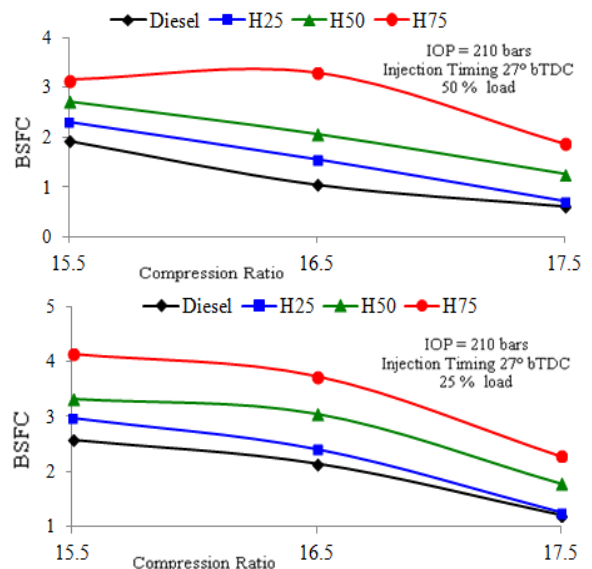
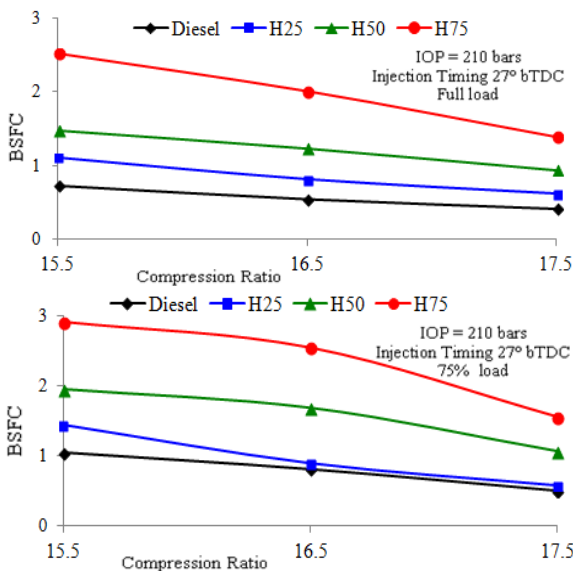
Biodiesel and its blends results in decreased brake thermal efficiency as compared to diesel over the entire range of compression ratio., which is as per expected, due to oxygen present in the Honne oil molecules improves the combustion characteristics but poor volatility affect the homogeneity of air fuel mixture which in turn lower the heat released rate thereby reduction in brake thermal efficiency than diesel. Also the lower heating value of biodiesel leads to decrease in brake thermal efficiency.

For the full load condition, the highest  $\eta_{bth}$  obtained is 20.2% for diesel, 16.12% for H25, 14.1% for H50 and 11.03% for H75 , all at compression ratio 17.5, this is due to higher compression ratio, higher will be peak pressure, and higher conversion of energy into to work., as compared to all other lower compression ratio. The lowest  $\eta_{bth}$  obtained is, 14.48% for diesel, 13.23% for H25, 12.11% for H50, and 9.73% for H75, all at compression ratio 15.5.

The multiple regression equation with three input variable, Blend, CR and Load conditions for Brake Thermal Efficiency (Bth Eff) is,

$$Bth\ Eff = - 18.2 + 1.34\ CR - 9.83\ Blend + 4.61\ Load$$

**C. Variation of Brake Specific Fuel Consumption**



The brake specific fuel consumption (BSFC) decreases with the increase in compression ratio, as expected. This is because of at higher compression ratio power generated is more, with respect to fuel consumption rate.

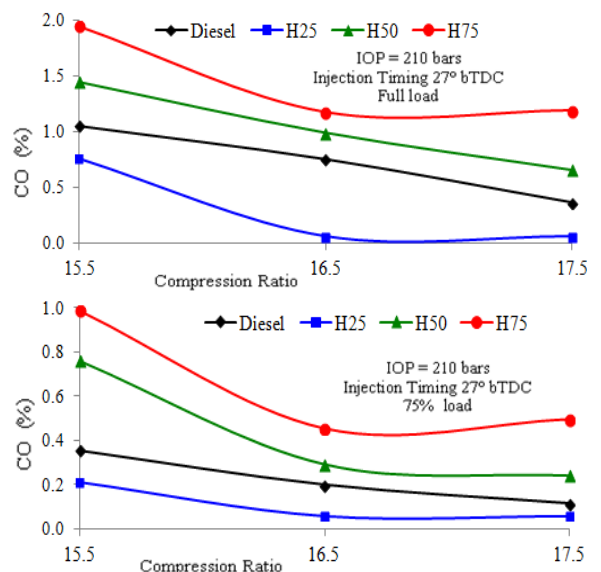
Figures shows that, BSFC for biodiesel and its blends are higher than that of diesel. This is due to lower heating value of biodiesel, lower the power generation for the same fuel consumption rate as compared to diesel.

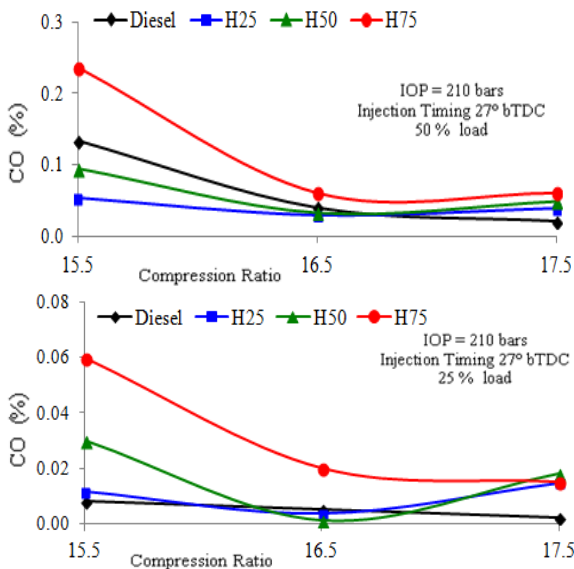
For the full load condition, the highest BSFC obtained is 0.72Kg/KW-h for diesel, 1.11 Kg/KW-h for H25, 1.46 Kg/KW-h for H50 and 2.52 Kg/KW-h for H75 , all at compression ratio 15.5, this is due to lower compression ratio, lower will be conversion of energy into to work, and higher will be the fuel consumption as compared to all other higher compression ratio. The lowest BSFC obtained is 0.41Kg/KW-h for diesel, 0.61Kg/KW-h for H25, 0.93 Kg/KW-h for H50 and 1.39 Kg/KW-h for H75 , all at compression ratio 17.5.

The multiple regression equation with three input variable, Blend, CR and Load conditions for Brake Specific Fuel Consumption (BSFC) is,

$$BSFC = 11.1 - 0.560\ CR + 2.37\ Blend - 0.560\ Load$$

**D. Variation of Carbon Monoxide (CO) Emission**





The percentage of CO emission of the biodiesel and its blends for low compression ratio increases and lower for high compression ratio.

For full load condition, when the compression ratio is varied from 15.5 to 17.5, the highest CO emission obtained is 1.06% for diesel, 0.77% for H25, 1.45% for H50 and 1.95% for H75, all are at the compression ratio of 15.5.

The lowest CO emission obtained is 0.37% for diesel, 0.06% for H25, 0.66% for H50 and 1.19% for H75, all are at the compression ratio of 17.5.

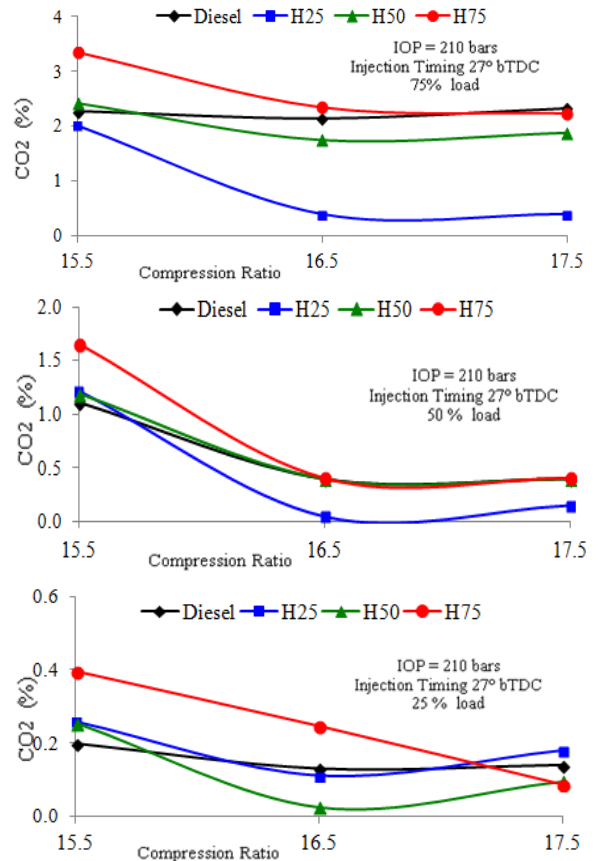
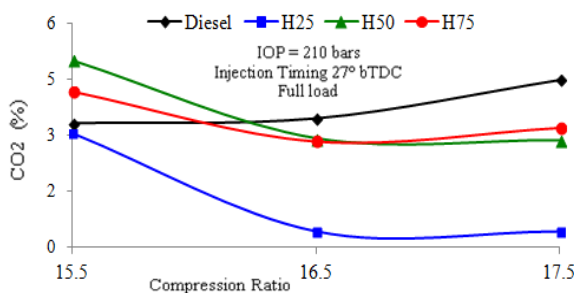
The effects of compression ratio on CO emissions for all engine load conditions are shown in Figures. The CO emissions are higher at lower compression ratio, however, decreased at higher compression ratio. This is due to relatively complete combustion takes place at higher compression ratio.

The CO emissions for biodiesel and its blends are higher, compared to diesel over the entire range of fuel blends, except H25, due to poor volatility of biodiesel resulting in poor mixing, rich pockets formed in combustion chamber, and consequently, poor combustion, which leads to higher CO emission.

The multiple regression equation with three input variable, Blend, CR and Load conditions for Carbon Monoxide (CO) is,

$$CO = 4.23 - 0.359 CR + 1.55 Blend + 0.631 Load$$

**E. Variation of Carbon Dioxide (CO2) Emission**



From the figures, the biodiesel and its blends emits lower percentage of CO2 as compared to diesel at higher compression ratio, this is because of the vegetable oil contains oxygen contents in it, so the carbon content is relatively lower in the same volume of fuel consumed at the same compression ratio, due to this CO2 emissions would have been decreased compared to diesel.

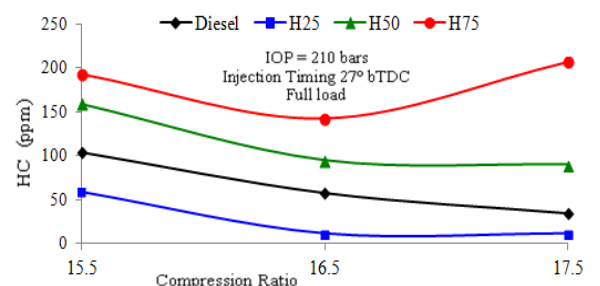
At lower compression ratio, incomplete combustion of high carbon content diesel fuel causes less CO2 emissions as compared to biodiesel and its blends, but in the present work CO2 emissions of H25 blend which have minimum biodiesel, shows lowest CO2.

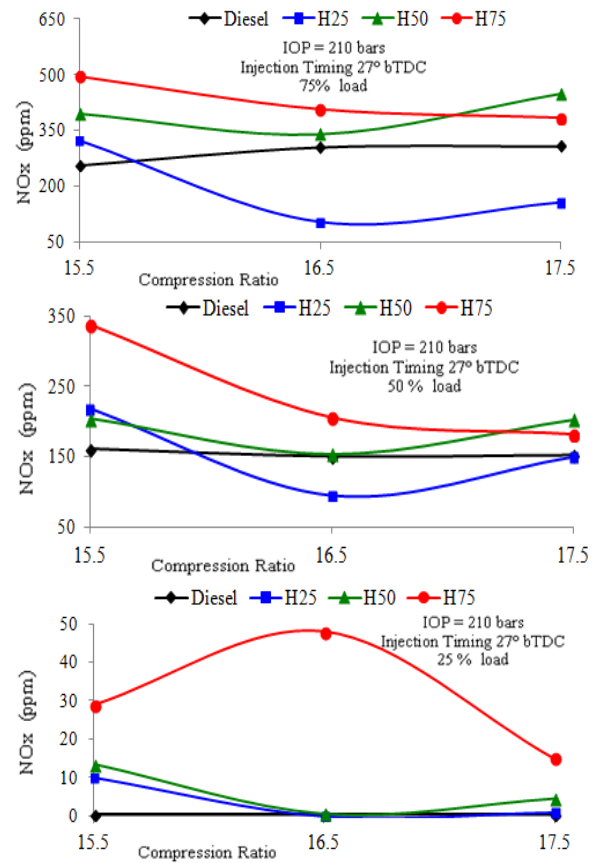
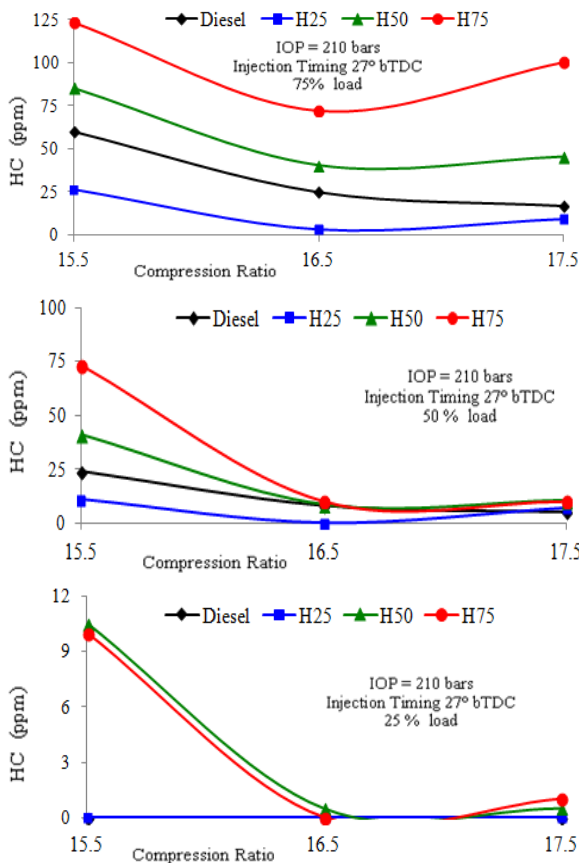
For full load condition, the highest CO2 emission obtained is 4.48% for diesel with lowest emission obtained is 0.41% for H25, 2.86% for H50 and 2.84% for H75, all are at the compression ratio of 17.5. The lowest CO2 emission obtained is 3.32% for diesel, with highest emission obtained is 3.05% for H25, 5.0% for H50 and 4.15% for H75, all are at the compression ratio of 15.5.

The multiple regression equation with three input variable, Blend, CR and Load conditions for Carbon Dioxide (CO2) is,

$$CO2 = 10.3 - 0.790 CR + 3.18 Blend + 1.21 Load$$

**F. Variation of Hydro Carbon (HC) Emission**





The HC emission decreases with increase in compression ratio for the entire range of fuels, this is due to the complete combustion of fuel at a higher compression ratio, hence less amount of HC will emits.

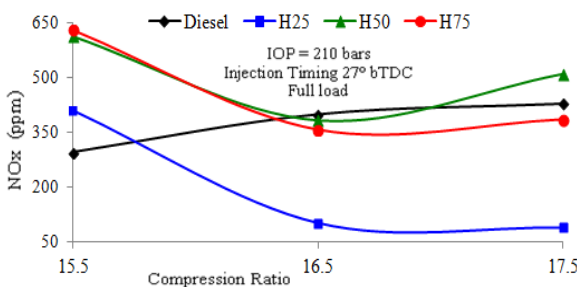
For the full load condition, the highest HC emission obtained is 103ppm for diesel 59ppm for H25, 160ppm for H50 at compression ratio 15.5, and 207ppm for H75 at compression ratio 17.5. The lowest emission obtained is, 34ppm for diesel, 11ppm for H25, 90ppm for H50, all these at compression ratio 17.5, but 142ppm for H75 at compression ratio 16.5.

The effects of compression ratio on HC emissions are shown in Figures. The HC emissions is higher at lower compression ratio, as expected, this is due to relatively less compression which retard the reactions of combustion, because of poor volatility, the poor spray characteristics, poor mixing, rich pockets formed in combustion chamber.

The multiple regression equation with three input variable, Blend, CR and Load conditions for Hydro Carbon (HC) is,

$$HC = 294 - 28.0 CR + 185 Blend + 59.3 Load$$

**G. Variation of Oxides of Nitrogen (NOx) Emission**



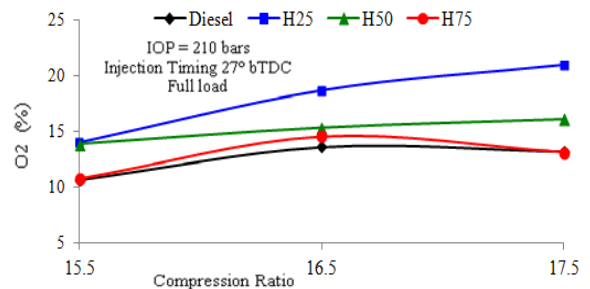
From the figures, it is observed that the NOx emission for entire range of fuel is higher at the compression ratio 15.5, this is due to highest temperature is observed at this compression ratio and at compression ratio 17.5, as the higher peak temperature observed with higher compression ratio.

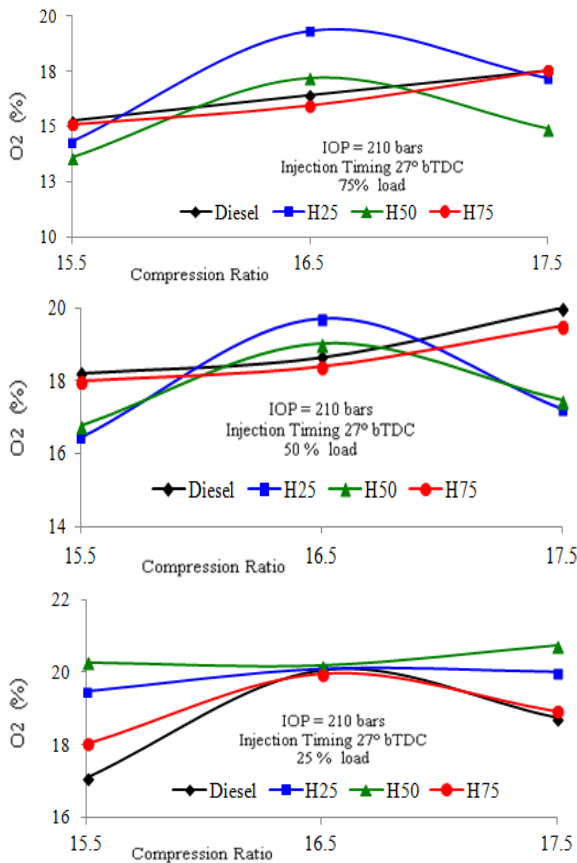
For the full load condition, the highest NOx emission obtained is 429ppm for diesel at compression ratio 17.5, and 409ppm for H25, 612ppm for H50 and 630ppm for H75 , all about compression ratio 15.5. The lowest emission obtained is, 400ppm for diesel, 102ppm for H25, 384ppm for H50, 358ppm for H75, all at compression ratio 16.5, as expected due to lowest temperature is obtained at compression ratio 16.5.

The multiple regression equation with three input variable, Blend, CR and Load conditions for Oxides of Nitrogen (NOx) is,

$$NOx = 1339 - 94.3 CR + 541 Blend + 106 Load$$

**H. Variation of Residual Oxygen (O2) Emission**





Figures shows that O<sub>2</sub> emission increases continuously with increases in compression ratio, this is due to increases in compression ratio, there is complete combustion thus oxygen requirement is mainly for CO<sub>2</sub>, but at lower compression ratio, there is more oxygen used in formation of CO, NO<sub>x</sub> in addition to that of CO<sub>2</sub>, thus oxygen content in exhaust gases is decreased.

Biodiesel and its blends shown higher O<sub>2</sub> emission as compared to diesel for full load conditions, this is because of vegetable oil contains oxygen content in it, so the overall carbon content is relatively lower, thus excess oxygen is remains in exhaust emissions.

For the full load condition, the highest O<sub>2</sub> emission obtained is 13.21% for diesel, 20.92% H<sub>25</sub>, 16.09% for H<sub>50</sub> and 13.17% for H<sub>75</sub>, all at compression ratio 17.5.

The lowest emission obtained is 10.68% for diesel, 14.02% H<sub>25</sub>, 13.87% for H<sub>50</sub> and 10.76% for H<sub>75</sub>, all at compression ratio 15.5.

The multiple regression equation with three input variable, Blend, CR and Load conditions for Oxygen (O<sub>2</sub>) is,  

$$O_2 = -19.7 + 2.52 CR - 5.23 Blend - 1.07 Load$$

## V. CONCLUSION

The study aims to evaluate the suitability of using biodiesel as an alternative fuel in VCR engine. Experimental investigations were carried out on the operating characteristics of the engines. The following conclusions are drawn from the investigations,

- Biodiesel and its blends results in slightly decreased brake thermal efficiency as compared to diesel over the entire range of compression ratio. –

This is due to biodiesel from *Calophyllum Inophyllum* (Honne) oil, have poor volatility result in poor atomization and poor spray characteristics, which lead to poor homogeneity of air fuel mixture which in turn lower the heat

released rate thereby reduction in brake thermal efficiency than that of diesel.

- BSFC for biodiesel and its blends are higher than that of diesel. –

This is due to lower heating value of biodiesel, lower the power generation for the same fuel consumption rate as compared to diesel.

- Exhaust Gas Temperature, EGT, for the biodiesel and its blends found lower at all conditions as compared to diesel. –

This could be due to low viscosity of biodiesel, which improve the spray formation in combustion chamber and thus leads to a less dominant diffusion combustion phase than diesel.

- The CO emissions are higher at lower compression ratio, and decreased at higher compression ratio. –

This is due to relatively complete combustion takes place at higher compression ratio.

- The CO emissions for biodiesel and its blends are higher, compared to diesel over the entire range of fuel blends. –

This is due to poor volatility of biodiesel resulting in poor mixing, rich pockets formed in combustion chamber, and consequently, poor combustion, which leads to higher CO emission

- The biodiesel and its blends emits lower percentage of CO<sub>2</sub> as compared to diesel at higher compression ratio. –

This is because of the vegetable oil contains oxygen contents in it, so the carbon content is relatively lower in the same volume of fuel consumed at the same compression ratio.

- The HC emission decreases with increase in compression ratio for the entire range of fuels, and for biodiesel and its blend it is higher than diesel. –

This is due to the complete combustion of fuel at a higher compression ratio, hence less amount of HC will emits. Biodiesel and its blends, due to poor volatility and poor mixing retard the chemical reaction which results in higher HC emission as compared to diesel.

- The NO<sub>x</sub> emission for entire range of fuel is higher at low compression ratio this is due to highest temperature is observed at this compression ratio. But the expected was, highest NO<sub>x</sub> emission obtained at highest compression ratio as the higher peak temperature observed with higher compression ratio.

- The O<sub>2</sub> emission increases continuously with increases in compression ratio –

This is due to increases in compression ratio, there is complete combustion thus oxygen requirement is mainly for CO<sub>2</sub>, but at lower compression ratio, there is more oxygen used in formation of CO, NO<sub>x</sub> in addition to that of CO<sub>2</sub>, thus oxygen content in exhaust gases is decreased.

- Biodiesel and its blends shown higher O<sub>2</sub> emission as compared to diesel –

This is because of vegetable oil contains oxygen content in it, so the overall carbon content is relatively lower, thus excess oxygen is remains in exhaust emissions.

From the above conclusions, it is proved that the biodiesel could be used as an alternative fuel in VCR engine without any engine modifications.

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