Experimental Investigation of Performance and Emission Characteristics of Undi Oil Biodiesel on VCR Diesel Engine

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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 called natural fuel may be a good source or substitute for fossil fuel in future. An experiment is conducted to obtain the operating and emission characteristics of Undi Oil Biodiesel on Variable Compression Ratio (VCR) engine run on various blends of biodiesel, compression ratios and load conditions. From the comparison of results, 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 can be fixed based on the experimental results obtained in the engine since the findings of the present research work infer that the biodiesel obtained from Undi oil is a promising alternative fuel for direct-injection four-stroke VCR diesel engine.

Key Words: Biodiesel, Undi Oil, Transesterification, Fuel Blends, Compression Ratio, Engine Load, Performance and Emissions, VCR Diesel Engine.

1 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 (NOx) 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, called B20, is currently the most widely used form of biodiesel.

Although several oil bearing trees like Karanja, Mahua, Polang, Kusum, Neem, Simarauba, Sal, Linseed, Castor, Baigaba, Jatropha Curcas etc. are native to India, systematic propagation and processing of these seeds is very important in view of large scale commercial production of bio-fuels.

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

The main objective of present work is to analyze the engine emission characteristics of diesel engines fuelled with biodiesel produced from 'Undi 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.

2 Material and Method

Undi oil contains 19.58% free fatty acids. The methyl ester is produced by chemically reacting undi oil with an alcohol (methyl), in the presence of catalyst (Sodium Hydroxide). A two stage process is used for the transesterification of undi oil.

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 57ºC in a closed reactor vessel. The oil is first heated to 50ºC 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 55-57ºC 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).

The separated biodiesel from the above-mentioned method contains various impurities like traces of glycerol, unused methanol, soap particles, etc. Water washing is carried out to remove all impurities. Air bubble wash is one of the methods normally recommended in the laboratory level. In this method, the impure biodiesel is placed in a beaker initially. Water is added slowly through the side wall of the beaker (both are immiscible). It is ensured that the equal amount of water is added above the level of biodiesel. Air is made to pass through the biodiesel and the water from the bottom of the beaker with the help of a bubbler (electrically operated).

The air will then take away all impurities from the biodiesel; they will move up as the bubbles move up, and they are added in the water. The unused methanol will be diluted in water. The traces of glycerol and soap particles make the water to become like soap water. Once the water becomes like soap water, the bubbler is stopped. After allowing some time for impurities to settle, the biodiesel is drained from the separating funnel, and pure biodiesel will be directly used, with or without blending, in the engine.

3 METHODOLOGY

As per the present authors' knowledge the use of blends of Undi Oil Methyl Ester – UOME in diesel engine at various load conditions and blend proportion are not reported in the literature. The objective of the present work is to study through experiments on the eimmision characteristics of CIME blends in direct injection (DI) diesel engine at various load.

TABLE I: BIODIESEL BLENDS USED FOR EXPERIMENTATION

Blend Type	***Blend***	***IOP in bars***	***Injection Timing in degree bTDC***	***Compression Ratio***	***Engine Load in KW***
H00	100% Diesel	210	27	14.5 : 1	0.75
H25	25% CIME + 75% Diesel			15.5 : 1	1.50
H50	50% CIME + 50% Diesel			16.5 : 1	2.25
H75	75% CIME + 25 Diesel			17.5 : 1	3.0

FIGURE-I: H00
(DIESEL)

FIGURE-II: H25
(25% UOME+75%DIESEL)

FIGURE-III: H50
(50% UOME+50%DIESEL)

FIGURE-IV: H75
(75% UOME+25%DIESEL)

The properties of H100 (UOME) and Diesel were determined as per the methods approved by Bureau of Indian Standards.

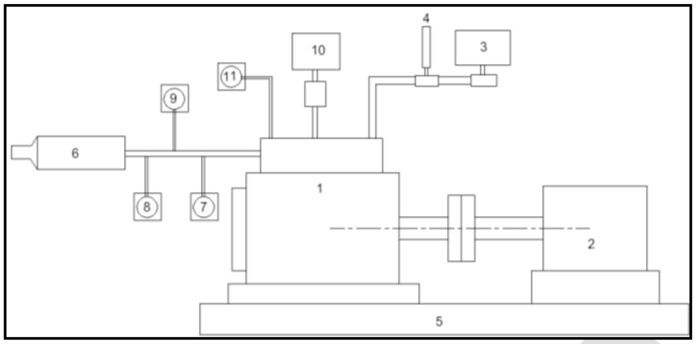
TABLE II: CHARACTERISTICS OF FUEL USED

Parameter	***Test Standard***	***Diesel (H00)***	***UOME (H100)***	***Undi Oil***
Density at 15ºC (gm/cc)	IS 1448 (P16) 2007	0.835	0.8653	0.9363
Kinematic Viscosity at 40ºC (cst)	IS 1448 (P25) 2007	3.5	1.744	51.58
Calorific Value (MJ/Kg)	IS 1448 (P6) 2007	43.00	35.37	40.27
Flash Point (ºC)	IS 1448 (P69) 2013	44	8.5	220

TABLE III: ENGINE SPECIFICATIONS

Sr. No.	***Description***	***Specification***
1	Make	Rocket Engineering Model VRC-1
2	Bore	80 mm
3	Stroke	110 mm
4	Swept Volume	553 mm
5	RPM	1500
6	Brake Horse Power	5 HP
7	Compression Ratio	17.5 : 1
8	Fuel Oil	High Speed Diesel
9	Coefficient of Discharge	0.65
10	Water Flow Transmitter	0 to 10 lit./min.
11	Air Flow Transmitter	0 to 250 wc
12	Piezo Sensor	0 to 5000 psi with low noise cable
13	Software	Labview

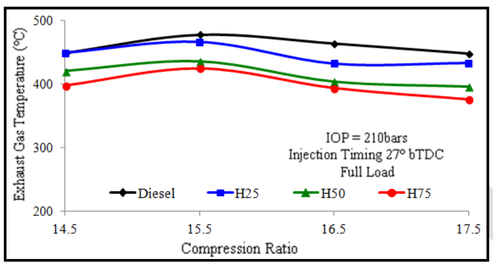
FIGUREI: ENGINE SETUP

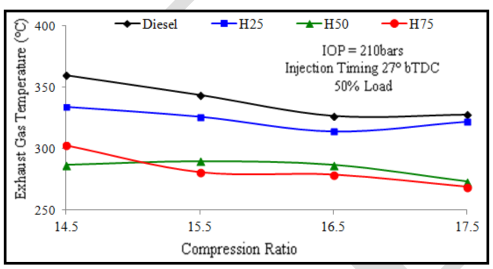


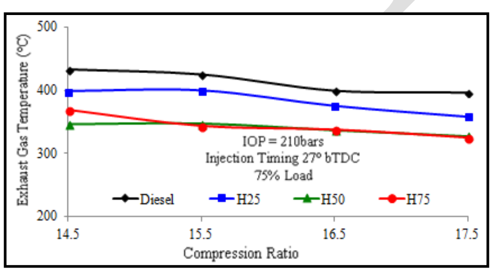
1. Test Engine, 2. Electrical Dynamometer, 3. Fuel Tank,
4. Fuel Burette, 5. Test Bed, 6. Silencer, 7. Smoke Meter,
8. HC/CO/NOx/CO2/O2 Analyzer, 9. Exhaust Temperature Sensor,
10. Air Flow Meter, 11. Stop Watch

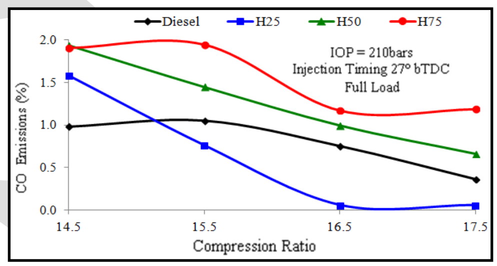
4 REULTS AND DISCUSSION

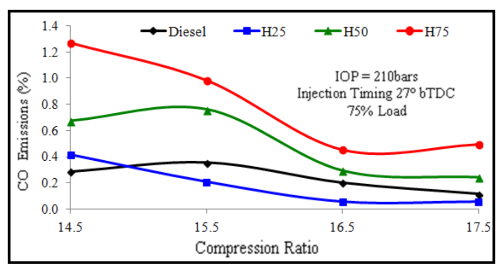
4.1 Variation of Exhaust Gas Temperature

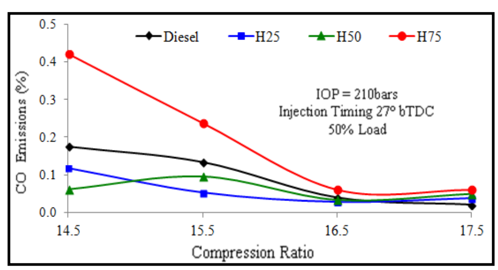


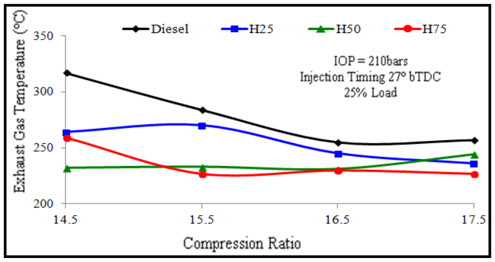


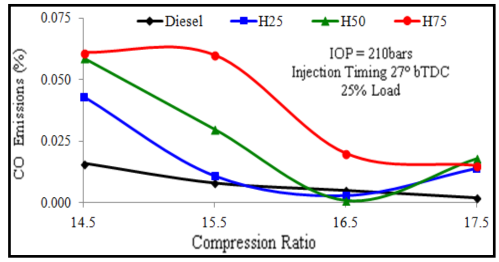












The result indicates that the variation in exhaust gas temperature is very minimal and showing the same trend at full load condition, but partial load condition upto 50% load, is distracted.

For full load condition, when the compression ratio is varied from 14.5 to 17.5, the highest temperature obtained is 476°C for diesel, 467°C for H25, 434°C for H50 and 422°C for H75, all are at the compression ratio of 15.5.

The lowest temperature obtained is 446°C for diesel, 434°C for H25, 394°C for H50 and 373°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 Figure, shows 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 formation 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,

$$CO = 2.12 - 0.462\ Blend - 0.144\ CR + 0.480\ Load$$

4.2 Variation of CO Emission

The percentage of CO emission for low compression ratio increases due to the rising temperature in the combustion chamber. The CO emission of the biodiesel and its blends are found to be lower for high compression ratio.

For full load condition, when the compression ratio is varied from 14.5 to 17.5, the highest CO emission obtained is 1.054% for diesel, 1.585% for H25, 1.938% for H50 and 1.905% for H75, all are at the compression ratio of 14.5.

The lowest CO emission obtained is 0.365% for diesel, 0.06% for H25, 0.066% for H50 and 1.187% for H75, all are at the compression ratio of 17.5.

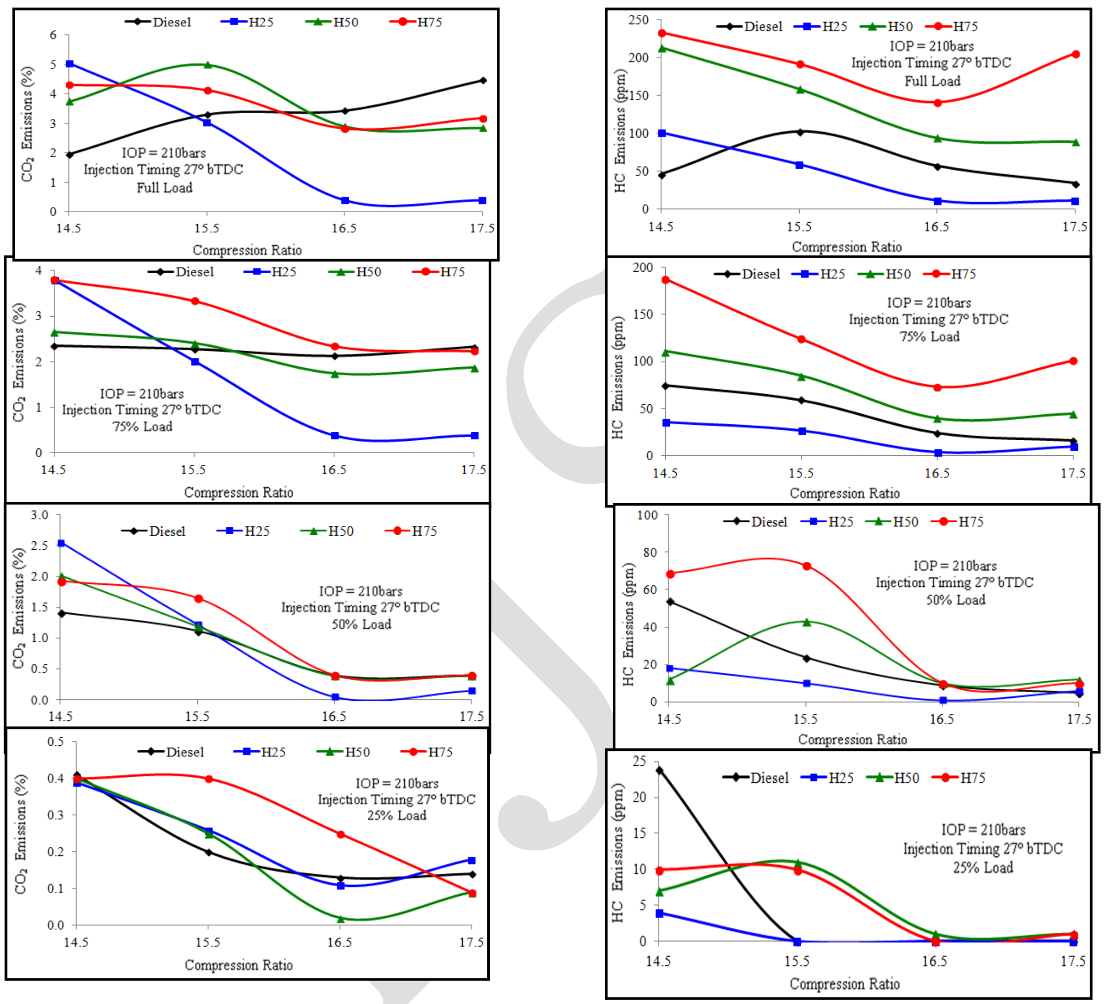
The effects of compression ratio on CO emissions for all engine load conditions are shown in Figures. The CO emissions are higher at lower compression ratio, however, decreased at higher compression ratio. This is due to relatively complete combustion takes place at higher compression ratio.

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,

$$CO = 2.12 - 0.462\ Blend - 0.144\ CR + 0.480\ Load$$

4.3 Variation of 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 highest CO2. This requires further investigations.

For full load condition, the highest CO_2 emission obtained is 4.47% for diesel with lowest emission obtained is 0.4% for H25, 2.86% for H50 and 3.19% for H75, all are at the compression ratio of 17.5.

The lowest CO_2 emission obtained is 1.96% for diesel, with highest emission obtained is 5.04% for H25, 3.75% for H50 and 4.32% for H75, all are at the compression ratio of 14.5.

The multiple regression equation with three input variable, Blend, CR and Load conditions for Carbon-dioxide (CO_2) is,

$$CO2 = 3.14 + 0.146 \text{ Blend} - 0.295 \text{ CR} + 1.82 \text{ Load}$$

4.4 Variation of 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 at compression ratio 15.5, and 100ppm for H25, 214ppm for H50 and 235ppm for H75 , all at compression ration 14.5.

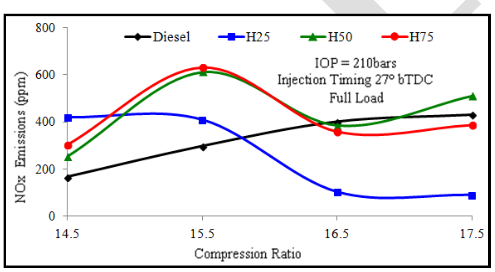
The lowest emission obtained is, 34ppm for diesel, 10ppm for H25, 89ppm for H50, all these at compression ratio 17.5, but 142ppm for H75 at compression ratio 16.5.

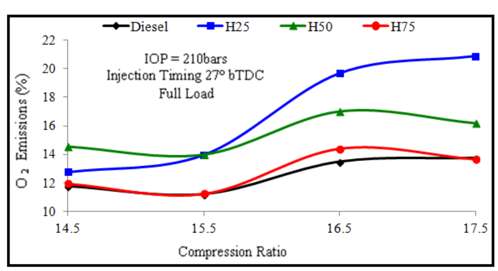
The effects of compression ratio on HC emissions are shown in Figures. The HC emissions is higher at lower compression ratio, as expected, this is due to relatively less compression which retard the reactions of combustion, because of poor volatility, the poor spray characteristics, poor mixing, rich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

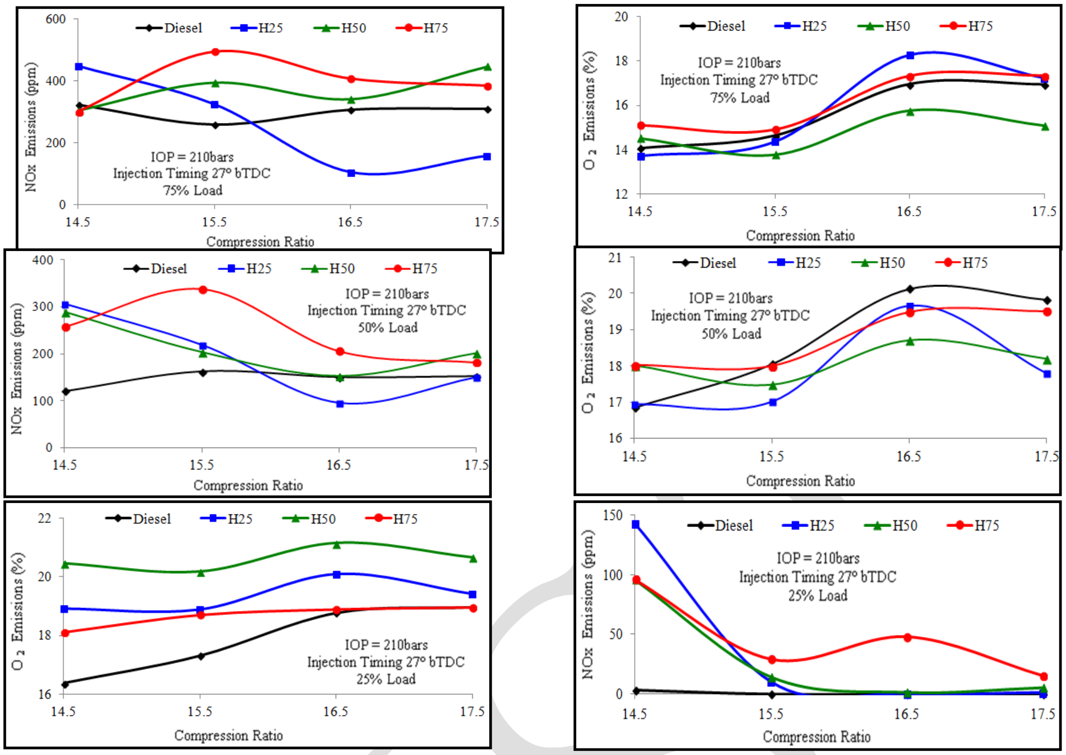
The multiple regression equation with three input variable, Blend, CR and Load conditions for Hydro-Carbon (HC) is,

$$HC = 228 - 79.9 \text{ Blend} - 13.2 \text{ CR} + 45.2 \text{ Load}$$

4.5 Variation of NO_x 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. But the expected was, highest NOx emission obtained at highest 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 430ppm for diesel at compression ratio 17.5, and 419ppm for H25, 611ppm for H50 and 629ppm for H75 , all about compression ration 15.5.

The lowest emission obtained is, 166ppm for diesel at compression ratio 14.5, 89ppm for H25 at compression ratio 17.5, and 250ppm for H50, 301ppm for H75, both at compression ratio 14.5.

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

$$NOx = 19 - 67.3\ Blend - 6.7\ CR + 199\ Load$$

4.6 Variation of O_2 Emission

Figures shows that O2 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 CO2, but at lower compression ratio, there is more oxygen used in formation of CO, NOx in addition to that of CO2, thus oxygen content in exhaust gases is decreased.

Biodiesel and its blends shown higher O2 emission as compared to diesel for full load conditions, this is because of vegetable oil contains oxygen consent in it, so the overall carbon content is relatively lower, thus excess oxygen is remains in exhaust emissions.

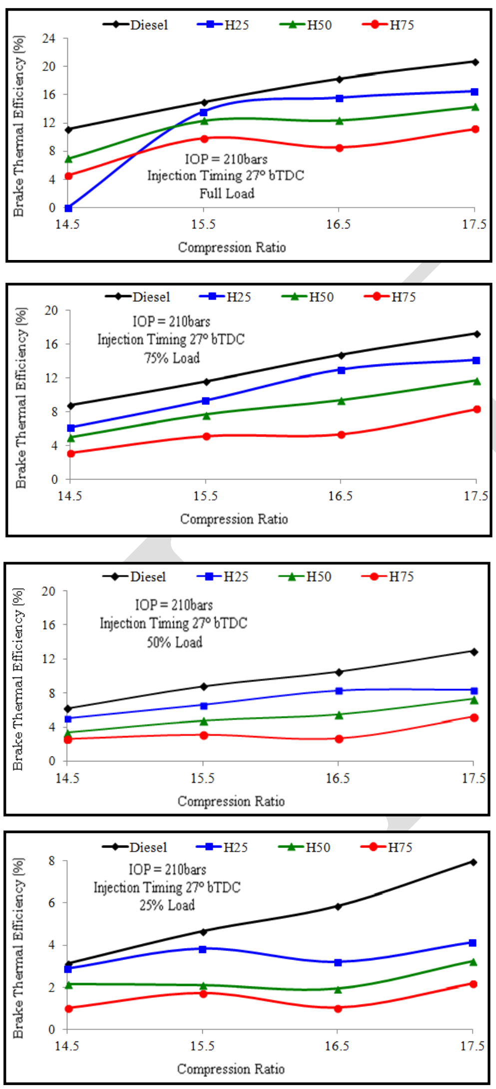
For the full load condition, the highest O2 emission obtained is 13.73% for diesel, 20.87% H25, both at compression ratio 17.5, 17.03% for H50, 14.40% for H75, both at compression ratio 16.5.

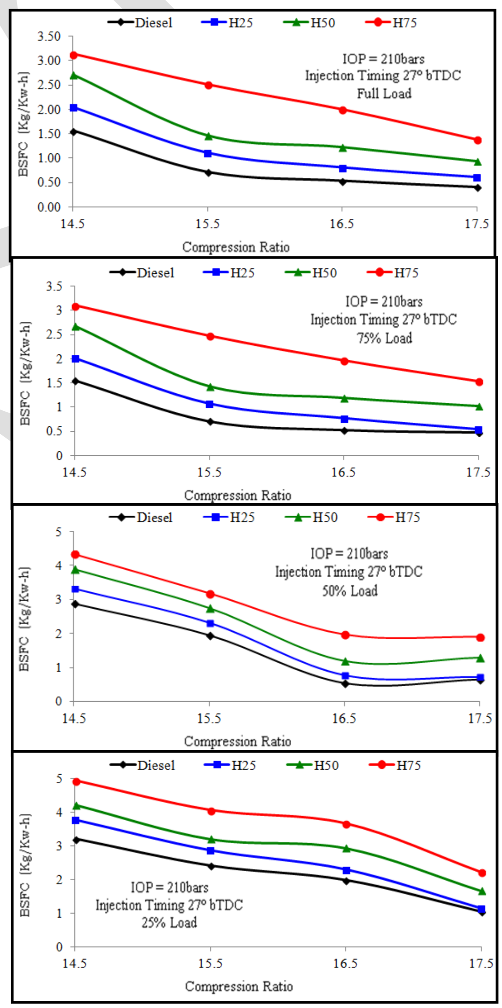
The lowest emission obtained is 11.76% for diesel, 12.76% H25, both at compression ratio 14.5, 13.97% for H50, 11.24% for H75, both at compression ratio 15.5.

The multiple regression equation with three input variable, Blend, CR and Load conditions for Oxygen (O2) is,

$$O2 = 10.7 - 1.16\ Blend + 0.706\ CR - 2.44\ Load$$

4.7 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 Calophyllum Inophyllum oil molecules improves the combustion characteristics but poor volatility result in poor atomization and poor spray characteristics. The poor spray pattern may 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 injection of higher quantities of fuel as compared to diesel for the same load conditions hence, decrease in brake thermal efficiency.

For the full load condition, the highest ηbth obtained is 19.70% for diesel, 16.58% for H25, 12.86% for H50 and 9.92% for H75 , all at compression ration 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 ηbth obtained is, 10.11% for diesel, 7.92% for H25, 6.48% for H50, and 4.31% for H75, all at compression ratio 14.5.

The multiple regression equation with three input variable, Blend, CR and Load conditions for Brake Thermal Efficiency (η_{bth}) is,

Bth Eff = - 37.4 + 7.31 Blend + 2.14 CR + 3.29 Load

4.8 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 1.57Kg/KW-h for diesel, 2.05 Kg/KW-h for H25, 2.72 Kg/KW-h for H50 and 3.14 Kg/KW-h for H75 , all at compression ratio 14.5, 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, 0.94Kg/KW-h for H50 and 1.38Kg/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 = 15.2 - 1.89 Blend - 0.668 CR - 0.644 Load

5 Conclusions

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 Undi 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_2 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_x 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_x emission obtained at highest compression ratio as the higher peak temperature observed with higher compression ratio.
- The O_2 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_2, but at lower compression ratio, there is more oxygen used in formation of CO, NO_x in addition to that of CO_2, thus oxygen content in exhaust gases is decreased.
- Biodiesel and its blends shown higher O_2 emission as compared to diesel – This is because of vegetable oil contains oxygen consent 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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