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Influence of compression ratio variation on diesel engines, performance and exhaust emission parameters devouring microalgae biodiesel blends

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The diesel engine performance as well as exhaust emission attributes are influenced by different structures. Impact of compression ratio and microalgae biodiesel blending proportion in petroleum diesel on variable compression ratio diesel engine performance and exhaust emission have been investigated in this study. The five blends of microalgae have been prepared on volumetric basis adopting standard procedure. The engine is fuelled with these five blends respectively to investigate their impact on engine performance and emission attributes. The experimentation has carried out at compression ratio 15.5, 16.5, and 17. For benchmarking comparison, the obtained results have been compared to test results found using petroleum diesel as fuel. Obtained experimental results have uncovered that the engine brake thermal efficiency increases as compression ratio increases for all the microalgae biodiesel blends. The brake specific fuel consumption diminishes with rise of compression ratio for tested fuel blends. The outcomes additionally show brake specific fuel consumption stay higher for blends and increase with rise of biodiesel mixing percent contrasted with unadulterated diesel. At the point when compression ratio has expanded from 15.5 to 17.5, the hydrocarbons and carbon monoxides outflow have reduced radically and nitrogen oxides discharge increases.

Key words: Diesel engine, Algal biodiesel, Compression ratio, Performance characteristics, Emission characteristics

1 Introduction

Already scarce sources of conventional fuels including diesel have to be exhausted with the advent of upcoming era. Inferable from the way that these fuels are often accounted as exhaustible, researchers have apprehensive about the future status of these fuel which might set off an emergency for the power sector. Economists and environmentalists have not agreed with the political and financial issues related to the assessment of most of these oils in concern with the environment. Many countries of the globe have confronting part of issues with respect to ecological effect and accessibility of non-renewable energy sources. Non sustainability, fast consumption and restricted for possible later use has the fundamental difficulties of existing non-renewable energy sources. The utilization of these traditional fuels essentially in transportation area has driven unfavorable impact on environment[1]. For this reason, the research community wherein line to look for clean elective fuels like alcohols, vegetable oils and biodiesel[2-4]. This is an unavoidable for the turn of events and usage of elective energy. Ethyl or methyl alcohol has been considered as one of the appropriate fuel replacement for diesel engines since it permits the diesel fuel to consume totally because of more oxygen content which improves engine performance[5]. Along with Methyl alcohol, ethyl alcohol, butanol are the alcohols which draw in the consideration of the majority of the researchers because of their simplicity of accessibility[6-8]. More works have completed with methanol from the previous years and less consideration has paid towards ethanol as well as butanol. Ethanol and butanol can be created from different sustainable assets like sugarcane molasses, corn, and wheat[9,10]. As a result of their high octane number, they have viewed as essentially great fuels for petrol engine. They have additionally have been viewed as reasonable fuels for CI Engines, fundamentally as blended with the diesel[11].

H Raheman and S V Ghadge[12] have examined the CR impression of on execution of Recardo E6 diesel engine. They have announced that the BSFC of engine has diminished when the compression ratio was expanded. MEL Kassa and MA Nemit[13] have examined influence of CR plus mixing proportion on engine for biodiesel and diesel. They have utilized mixing proportion 10,20,30,50 and compression ratio

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14, 16, 18 for examination. The BSFC for all mixes diminishes along with compression ratio increments and at examined compression ratio BSFC values stay more for higher mixes as the percent of biodiesel increments. Expansion of compression ratio value between 14 to 18 have brought about increment in values of BTE by 18.39, 27.48, 18.5 and 19.82 percent for the mixes B-10, B-20, B-30 and B-50 individually. The CO and HC discharges decreased and NO_X emanation expanded with compression ratio for every one of the mixes. N. R. Kumar et.al[14] have considered the influence of compression ratio plus EGR (Exhaust Gas Recirculation) on diesel engine attributes, they saw that the BTE increments and specific consumption of fuel diminishes as increment in compression ratio.

Greater the temperature and fuel molecule atomization has happened for higher CR; more will result be the Heat Release Rate (HRR)[15]. Due to combined increment in compression ratio and injection timing, inflation in BTE with bringing down the BSFC as well as exhaust gas emissions[16]. For most elevated CR of 18:1 and full load conditions, this tends to the value-added BTE, higher HRR as well as in absence of knock highest (peak) pressure[17]. Performance of engine has progressed for higher CR along with decrease in value of CO, may be because of improved fuel atomization[18]. As the CR increased by 20%, the temperature also increases, thus results better burning have leaded to lower in HC while increase in NOx emissions[19]. Upsurge in value of compression ratio has result in better BTE, peak pressure value and increased NOx exhaust emissions, but BSFC, value of CO and HC emissions diminishes[20]. The emissions of HC have been predominant for substandard compression ratio but lower for higher CR though NOx emissions were more at high CR[21]. At high compression ratio, the energy also increases[22], may be because of higher combustion chamber temperature due to high compression ratio, the emissions of CO will be lower[23].

The impact of CR and fuel injection pressure on the combustion, performance, and emission characteristics of a CI engine running on butanol/diesel (B/D) mixes has studied by K. Siva Prasad *et al.* [24]. According to their research, increasing the CR from 14 to 18 have enhanced in-cylinder pressure, net heat release (NHR), and brake thermal efficiency (BTE) for all biodiesel blends. With an increase in the CR from 14 to 18, soot, CO, and UBHC emissions have dropped, however NOx emissions have been increased. Debowski M. *et al.*[25] have measured the emissions from an engine running on biodiesel made from *Chlorella protothecoides* bio-oil. CO_2 emissions have found to be comparable for all fuels tested and to increase linearly with increasing engine load. When compared to rapeseed biodiesel, microalgae biodiesel has produced much less CO and has contributed to lower NOx emissions. Regardless of engine load, the engine driven by diesel had the maximum HC emission. It has much lower when the engine has driven by microalgae biodiesel than when it has fueled by rapeseed biodiesel at low engine loads. Abdul rahman Shakir Mahmood *et al.*[26] has examined the impact of changing the compression ratio on the performance and emissions of a single cylinder, 4-stroke CI engine running on maize oil biodiesel blends and pure diesel fuel. The results have indicated that, as the CR is increased, the BTE rises and the BSFC falls for all types of fuel. CO, HC, and smoke opacity emissions have reduced but CO_2 and NO_X emissions have increased at the same time that the CR and percentage of biodiesel blend have increased. G. V. More *et al.*[27] have conducted research to examine the combined impact of compression ratios on emission and performance parameters of a diesel engine employing ternary mixes versus diesel. The findings reveal that a greater compression ratio helps to reduce nitrogen oxide emissions while a lower compression ratio helps to reduce carbon monoxide emissions. With a larger amount of diethyl ether (2.4 and 3.2%), CR16 is more effective at reducing emissions while also improving performance.

Experiments on a single cylinder DI diesel engine have carried out by Mohankumar Subramaniam *et al.*[28]. Among the many blends examined, B20 reveals a closer match with diesel has leaded in improved thermal efficiency, reduced HC, CO, smoke, and particle emissions. Other emissions, such as nitrous oxide and carbon dioxide, have found to be slightly higher. The performance parameters and exhaust emissions of a diesel engine consuming biodiesel blends and diesel fuels have been examined by Avinash Kumar *et al.*[29]. In comparison to B20 and diesel fuels, B50 have demonstrated a drop in SFC, an increase in exhaust gas temperature, and a decrease in BTE. With increasing loads, the CO_2 proportion increased. In comparison to diesel, all of the mixes had reduced HCs. G V More *et al.*[30] have investigated the effects of different concentrations of diethyl ether (DEE) as an oxygenated ingredient in repurposed used cooking oil (RUCO) biodiesel and diesel blends on the characteristics of diesel engines. For a 0.8% concentration of DEE blend, the BTE increased by 16.06 % while the BSFC reduced by 4.12% according to the investigation. Furthermore, when compared to diesel fuel, the CI engine fed with biodiesel-DEE-diesel blends have showed a maximum reduction in CO, HC, and NOx emissions of 20.41%, 34.69% and 23.33% respectively. Due to the lower carbon content in ternary mixes, CO_2 emissions have lowered.

Though profound study has been carried out to analyze the influence of CR on the performance characteristics of a CI engine operating with various bio diesel blends, the case of microalgae biodiesel blends have not been cited and even in the available literature the parameters has not extensively investigated. In most of the research the effect of CR along with greater microalgae biodiesel blend fractions, on the performance and emission characteristics of single cylinder direct injection variable compression ratio CI engines has not been thoroughly explored and examined. The intense analysis of the reviewed literature reflects that this subject requires more investigation to explore promising outcome. To comply the need of unexplored features found in literature review this work has focused to investigate experimentally the effects of CR on the performance and emission characteristics of a VCR diesel engine operating with five microalgae biodiesel blends as fuel.

2 Materials and Methods

2.1 Raw Algae sample collection

Necessary quantity of raw algae was gathered from site of canals of salai mendha dam near Hingna, Nagpur District (MH, India)[31] as shown in Fig. 1. The gathered raw algae were cleaned totally to eliminate unfamiliar materials as shown in Fig. 1 (a). It is then dried as shown in Fig. 1 (b). After these dried algae was pounded to get homogeneous powder. These powdered algae were squashed over and over with hexane plus propanol dissolvable blend for lipid extrication. The extricated lipids were isolated from the algae and heated to remove the dissolvable. The leftover oil was exposed to the transesterification reaction.

2.2 Transesterification

Transesterification reaction was utilized to diminish the biodiesel oil viscosity. In this reaction alcohol was the main constituent, typically methyl or ethyl alcohol and either NaOH (sodium hydroxide) otherwise KOH (potassium hydroxide) were used as catalytic agent. The required Chemicals in this experimentation were purchased from local chemical sellers. In this experimentation KOH was utilized as catalyst and methyl alcohol for reaction. With microalgae oil, at 65°C, these two were kept for chemical reaction for duration of around 3 to 4 hours. The arrangement is made in such a way that proper mixing has happened throughout the chemical reaction. Two separate layers of algae biodiesel and glycerol were the results of this reaction. Biodiesel was at the top next to glycerol. The required biodiesel was isolated in the wake of sifting the glycerol by utilizing separator. Thus the biodiesel obtained was send test to know its physiochemical properties. The used transesterification chemical reaction was illustrated in Fig. 2.

This transesterification reaction was carried out in institute laboratory using mini biodiesel setup as shown in Fig. 3.

Fig. 1 — (a) Uniform slurry of algae, and (b) completely dried algae.

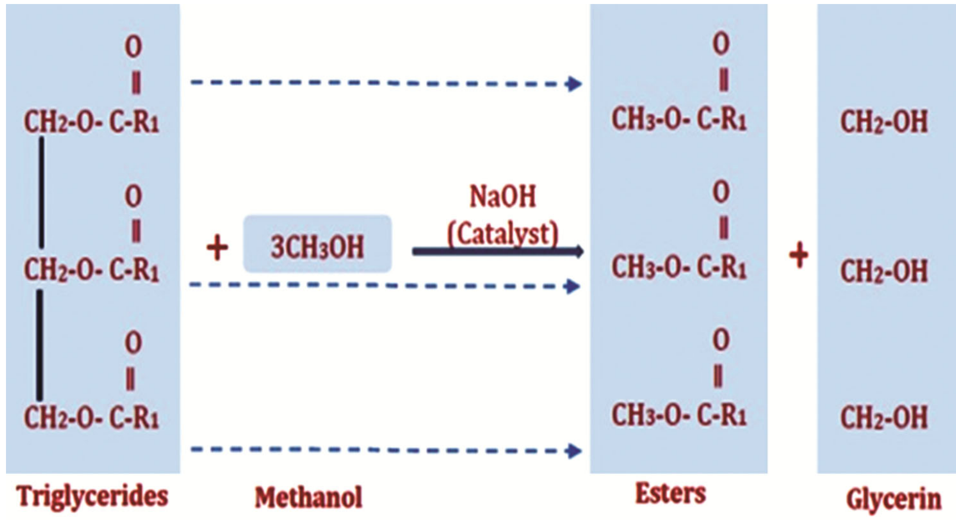

Fig. 2 — Biodiesel preparation chemical reaction (Transesterification).

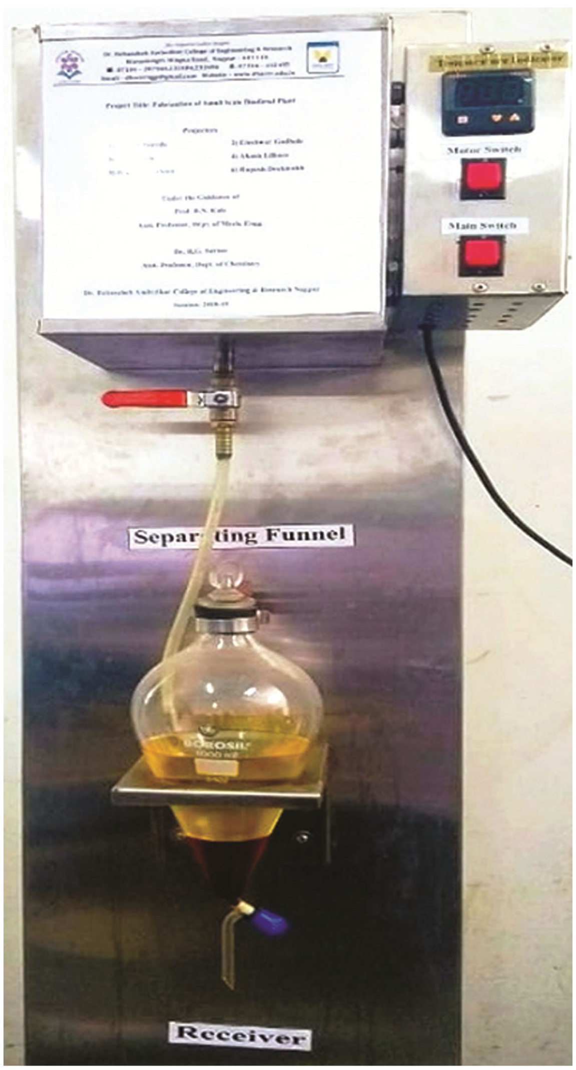

Fig. 3 — Mini biodiesel plant.

Table 1 — Microalgae biodiesel blends on volumetric basis

Blend of microalgae biodiesel	Contribution of microalgae biodiesel (volume, in Litre)	Contribution of petroleum diesel (volume, in Litre
MAB10	0.1	0.9
MAB20	0.2	0.8
MAB30	0.3	0.7
MAB40	0.4	0.6
MAB50	0.5	0.5

2.3 Blends Preparation

For experimentation on selected VCR diesel engine test rig, five blends of microalgae biodiesel were prepared on volumetric basis and they were particularized in Table 1.

The actual microalgae biodiesel blends were prepared on volumetric basis and were shown in Fig. 4.

2.4 Properties of Test Fuel

The chemical and physical properties of all five microalgae biodiesel blends as well as pure algal biodiesel were investigated adopting ASTM test conventions strictly in institute laboratory. The instruments/apparatus utilized for properties investigation were provided in Table 2. The microalgae biodiesel blends fuel properties were introduced in the Table 3.

2.5 Experimental test rig

The experimental test rig utilized during this investigation was Kirlosker made 4-stroke, vertical, water cooled type diesel engine as shown in Fig. 5 (a). The complete experimental set up was calibrated and installed by Apex Innovations Sangli (MH, India). Eddy current dynamometer was attached in lined with diesel engine for loading. The graduated burette was

Table 2 — Standard apparatus for biodiesel characterization and corresponding ASTM standards

Fuel Properties	Instrument used	Standard test method
Viscosity	Redwood viscometer	ASTM D445
Density	Pycnometer	ASTM D941
Flash point	Pensky Marten Closed Cup Apparatus	ASTM D93, For Small Scale-D3828, D6450
Fire point	Flash point apparatus	ASTM D93
Heating value	Digital bomb calorimeter	ASTM D240

Table 3 — Chemical as well as physical properties of blends of microalgae biodiesel[31]

Properties	Petro-diesel	Microalgae Biodiesel	MAB10	MAB20	MAB30	MAB40	MAB50
Kinematic viscosity @ 40°C	2.7	3.16	2.746	2.792	2.838	2.884	2.93
Cetane Number	49	48	48.9	48.8	48.7	48.6	48.5
Density at 15degree Celsius	830	881	835.1	840.2	845.3	850.4	855.5
Flash point (deg.cel)	64	150	72.6	81.2	89.8	98.4	107
Fire point (deg.cel)	71	83	72.2	73.4	74.6	75.8	77
Heating Value	42	41.5	41.95	41.9	41.85	41.8	41.75

Fig. 4 — Five test blends of microalgae biodiesel with petroleum diesel.

used for measurement of fuel consumption in unit time (i.e. time for 10 ml consumption of fuel). An orifice meter along with a U-tube manometer was installed through suction so as to record the consumption of air. Six thermocouples were provided to take the reading of temperatures at inlet and outlets. The temperatures, speed, load were displayed on panel board. By using multipoint selector switch on the engine panel confirm that all voltage values were properly displayed. There was temperature transducer to convert the voltage values in to respective temperature reading using parameter chart pasted on the panel. The parameter (*Multiplication Factor*) provided on the panel for temperature t_1 to t_4 is 25 whereas for t_5 and t_6 it is 250. The values displayed should show around ambient temperatures for t_1 andt_3[32].

There was a formula for temperature calculations, since it displays corresponding voltage. The formula was as per Eq. (1).

$$T = (Reading-1)\ X\ Multiplication\ Factor(\text{Parameter}) \quad \ldots (1)$$

Computerization data acquisition system was also provided for accurate and exact reading. The technical specification of experimental set up was provided in Table 4.

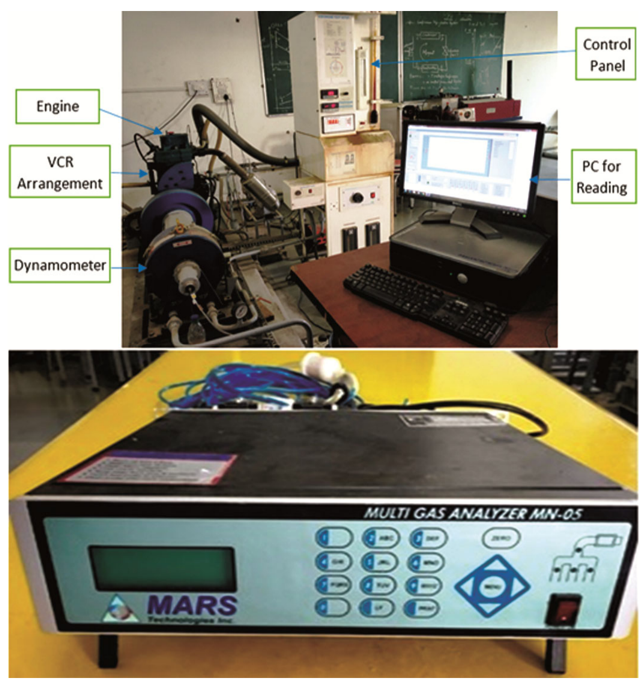

Fig. 5 — Experimental setup (a) computerized CI engine test rig[32], and (b) exhaust emission analyzer[33].

2.6 Procedure for performing an experimental performance test

The methods listed below should be followed with care in order to obtain accurate results.

Table 4 — Technical specification of experimental test rig[32]

Parameter	Specification
Product	Computerized Variable CR Engine test rig, single cylinder, four stroke
Product code	234
Engine	Make: Kirloskar oil engines, water cooling, power- 3.5 kW for 1500 rpm, stroke length :0.11 m, bore diameter: 0.0875 m, capacity :661 cc, Standard CR: 17.5:1, Altered to Variable CR engine , having range from 12 to 18
Dynamometer	water cooled , eddy current
Calorimeter	Pipe in pipe
Sensors for Temperature reading	RTD Type, PT100 as well as Thermocouple, K Type
Indicator for load	Digital, Range up to 50 Kg, with power supply of 230V, AC
Sensor for load reading	strain gauge type, Load cell, , range up to 50 Kg
Software	“Enginesoft LV”

- The water circulation for dynamometer cooling, along with engine and exhaust gas calorimeter was checked.
- Experimental test rig was started and kept it running for minimum 5 minutes.
- The compression ratio was adjusted at desired value.
- Reading at no load condition was noted.
- Load on engine was increased gradually by turning the loading knob provided on panel board.
- Waited for steady state (min.3-5 minutes) and then reading of temperature (t_1 to t_6), speed, load, calorimeter and engine jacket water flow rotameter, fuel flow (duration for 10 ml fuel consumption), and manometer were taken.
- Same procedure was followed to took reading for all necessary load conditions after reached steady state.
- After completing all of the reading, the engine's load to zero was gradually reduced.
- The procedure was repeated for next compression ratio according to the process outlined before.
- The readings were completed and appropriate calculations were carried out to obtained the results.

The formulae for basic calculations were discussed in next section.

Torque employed on the stator was measured and was calculated as per Eq. (2).

$$\mathrm{Torque(T)} = \mathrm{F} \times \mathrm{L} \quad \dots (2)$$

Where

F= Load in Newton
L= 250mm (Arm Length)

a. *Power*

Product of angular speed and torque was the power developed by an engine. It was calculated as using Eq. (3) given below;

$$Power(P) = 2\pi NT \quad \dots (3)$$

i. *Brake Power (BP)*

The power available at the engine output shaft was called brake power. This power can reliably resist the resistance or braking force of the application using the engine. Can be calculated using Eq. (4) given below;

$$BP = \frac{nP_{mb}\, LAN}{60} \quad \dots (4)$$

For calculation of Area (A), bore diameter d= 0.875m and length of bore l= 0.11m

b. *Specific Fuel Consumption (SFC)*

It was the amount of fuel consumed by engine to develop unit power. It was calculated by using Eq. (5) as under;

$$SFC = \frac{Mass\ of\ Fuel}{Brake\ Power} \quad \dots (5)$$

It was a very essential parameter since it clearly indicates the engine capacity to burn fuel for power production. It was always desirable that value of specific fuel consumption will be low.

c. *Thermal Efficiency (η_{th})*

Thermal efficiency was termed as the ratio of the work produced by the engine to the chemical energy or heat produced with fuel combustion in engine. It can be based on indicated power or braking power.

$$Brake\ Thermal\ Efficiency = \eta_{bth}$$

$$= \frac{BP}{m_f\ X\ CV} \quad \dots (6)$$

Eq. (6) has used to calculate the brake thermal efficiency.

All the above discussed parameters played a vital role in engine operation and its output so always taken into consideration while experimentation on engine using various fuel.

2.7 Emissions testing

To note down and observing parameters of emissions, ARAI approved Multi gas analyzer by MARS (Model: MN-05) as shown in Fig. 5 (b) was used. Technical specification, measurement range as well as accuracy were put forth in Table 5 and Table 6 respectively.

Figure 5 (b) displayed the Multi exhaust emission analyzer (made: MARS, Model No-MN-05) used to investigate the exhaust gas parameters. The standard procedure followed for emission readings was discussed below.

- Firstly, filter was checked. It should be dry, not damaged or dirty.
- The water trap and probe line must be water free. The probe sampling for ambient air was cleaned.
- RPM, RS-232 cable was connected properly.
- The gas analyzer was started and checked for water vapor, low flow, purging, zero calibration, oxygen cell status, flushing inlet path. All this was displayed on screen and then gone for leak check.
- After leak check was successfully displayed on screen, gone for HC, CO, CO_2etc. check.
- Measurement cycle was already being configured by system to separate each measurement.
- The probe was placed in to exhaust tail pipe and the engine was started for test.
- The results displaced on screen for all exhaust readings were noted down.
- Analyzer was provided with micro-printer for test report printer which enable printer to give an emission test report.

2.8 Changing compression ratio

The standard accessible engines (with static CR) may be changed by giving extra adaptable ignition space. There were various methods by using which this will be accomplished. Slanting engine chamber block strategy was unique method, in which where the CR can be altered without alteration in ignition/combustion phenomenon. Using this technique, the CR would be changed inside planned reach ceaselessly the engine.

2.8.1 Steps to change compression ratio

The arrangement provided to set desired compression ratio is displayed in Fig. 6, The basics steps to change compression ratio were given as under-

- Slightly slacken the 6 nos. vertical allen bolts (attachment headed) mounted on the two sides of the slanting chamber block.
- Adjuster lock nut should be loosened and the adjuster was turned with the use of spanner for slanting the chamber block.
- Required compression was adjusted by alluding the scale gave on the compression ratio marker (close to the adjuster)
- Now adjuster lock nut was tightened.
- All the 6 vertical allen bolts gently tightened up.

2.9 Experimental procedure for performance test

Following were the steps which should be meticulously adopted so as to get accurate results.

Table 5 — MARS Multi gas analyser specification[33]

Factor	Specification
Operating System	Peripheral interface controller (PIC) Micro Controller
Display	Liquid Crystal Display (LCD)
Interface	RS 485 and RS 232
Power Supply	230V AC.50Hz , 12V DC(Optional)
Dimensions (m)	0.45 X 0.3 X 0.12
Weight	Approximately 5Kg

Table 6 — Measurement Range Resolution of Multi Gas analyzer[33]

Factor	Range	Accuracy
Oxygen (O_2)	0 to 25% volume	0.1% volume
Carbon monoxides (CO)	0 to 9.99% volume	0.001% volume
Hydrocarbons (HC, propane)	0 to15000 ppm	1 ppm
Carbon dioxide (CO_2)	0 to 20% volume	0.01% volume
Nitrogen Oxides (NOx)	0 to 5000 ppm	1 ppm volume
Engine speed	500 – 6000 rpm	1 rpm
Lambda	0.200 – 2.000%	0.001

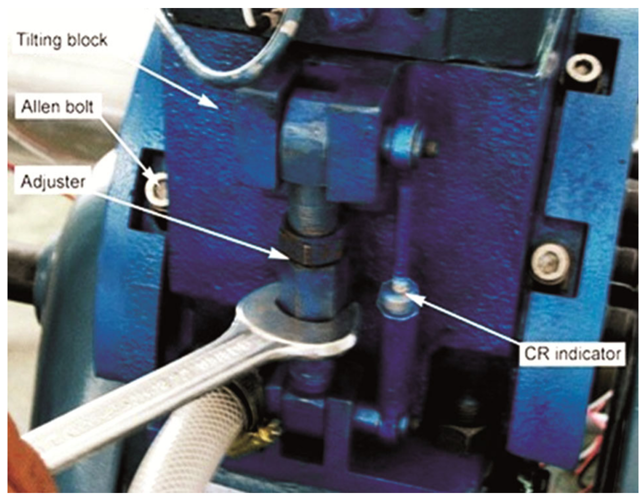

Fig. 6 — Adjustment of compression ratio [32].

- Firstly, the circulation of water for cooling of dynamometer (eddy current); engine and exhaust gas calorimeter was checked.
- Now the experimental set rig was started and kept it idle running for about 5 minutes.
- The reading on no load conditions was taken.
- The load was increased progressively using the knob provided on panel for loading.
- Waited to acquire steady state (about 3 min.) and after that the reading of temperatures (t_1 to t_6), Speed, Load, rotameter reading for calorimeter and engine jacket water flow, fuel flow (time for 10 ml fuel consumption), manometer reading were noted down.
- By waiting for each load for steady state all the readings were noted down.
- After finishing all the reading, engine load was brought to no load gradually.
- This is for one compression ratio. Now the desired compression ratio was adjusted as per procedure discussed as earlier.
- For new compression ratio all the previous steps were followed and the reading noted.
- Observation was completed and necessary calculations were done for results.

3 Results and Discussion

Five blends of microalgae (MAB10, MAB20, MAB30, MAB40 and MAB50) were tested as fuel in variable CR diesel engine experimental test rig. Petroleum diesel was also tested tor comparison purpose. The experimentation was repeated for three CR i.e. 15.5, 16.5 and 17.5. The experimental results obtained were discussed in following sections;

3.1 Performance Parameters

3.1.1 Brake Thermal Efficiency (BTE)

Figure 7 (a-c) showed the variety of brake thermal efficiency (BTE) for applied load at three distinctive CRs (CR: 15.5, CR: 16.5 and CR: 17.5). Brake thermal efficiency of engine demonstrated the rate of heat energy changed over to helpful mechanical energy. The below figures show that unadulterated diesel had higher BTE altogether CRs. At the point once, for microalgae biodiesel blends with diesel i.e. MAB10, MAB20, MAB30, MAB40 and MAB50, MAB10 was higher BTE as compared with other blends for almost every compression ratio. There was a variation of 10.57% in BTE in between MAB10 and petro diesel. Whereas the average variation was to 12.5%, 13.91%, 18.23% and 23% for MAB20, MAB30, MAB40 and MAB50 microalgae biodiesel

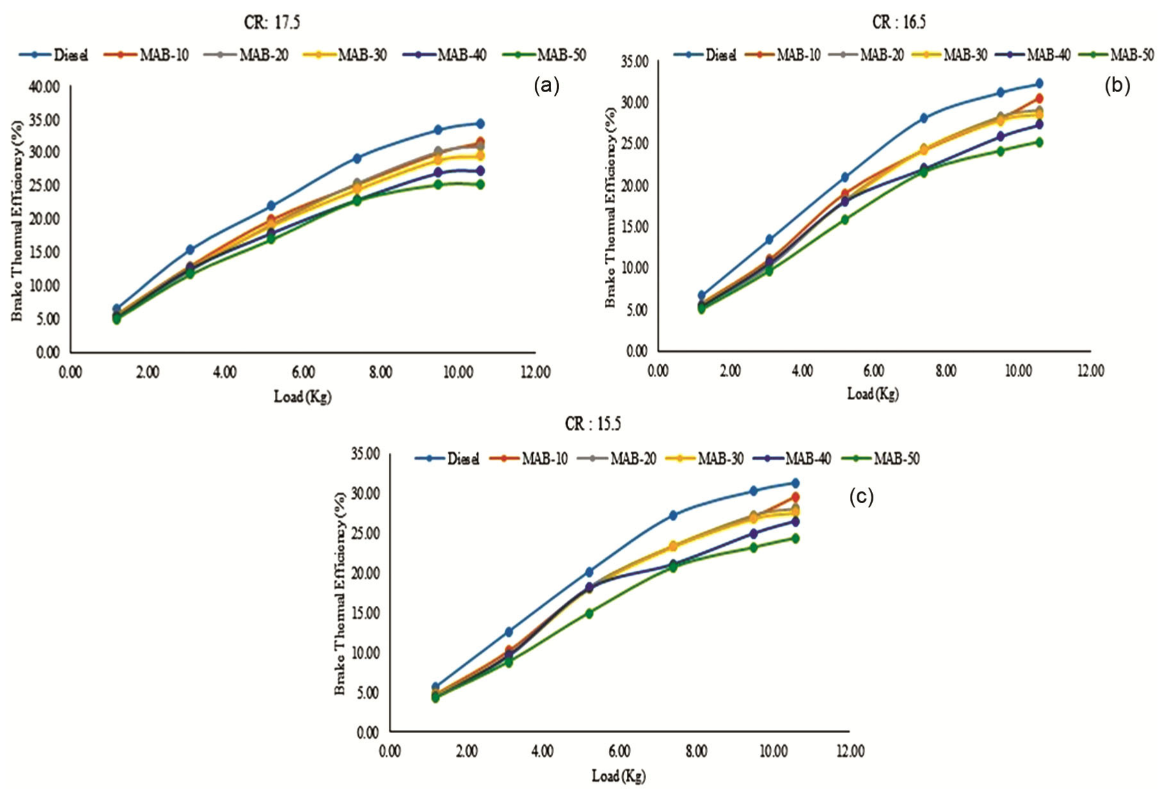

Fig.7 — BTE variation with respect to applied load for (a) CR 17.5, (b) CR 16.5, and (c) 15.5.

blends and petro diesel respectively. As per as this experimentation was concern MAB10 results were in closer circle of petroleum diesel and competitive. MAB 20 results followed the same trends as MAB10 with slight variations but deviates for other parameters. Since the viscosity of microalgae biodiesel was somewhat more in comparison with petro diesel, it resulted in deprived spray characteristics. Also lower heating value (Calorific Value), more volatility as well as indecorous mixing of air and fuel, were some parameters that may leads to declination in BTE[27-29].

3.1.2 Brake specific consumption of fuel (BSFC)

The Fig. 8 (a-c) showed the variety of brake specific fuel consumption (BSFC) against load for three diverse compression ratios (CR-15.5,16.5 and 17.5). For any engine, it was fuel efficiency which was directly related to brake specific consumption of fuel. It was the capacity of engine to combust fuel for producing rotary motion. The value of brake specific fuel consumption was infinite at no load condition whereas it decreases bit by bit with increased in load. For all tested fuels including petroleum diesel it was observed that, as the load increases BSFC decreases. In comparison with all fuels, petroleum diesel fuel consumption was less for compression ratio 15.5. Comparing all the microalgae biodiesel blends, MAB10 specific consumption of fuel was 0.5641 kg/kWh, while it is 0.5757 kg/kWh, 0.60008 kg/kWh, 0.6430 kg/kWh and 0.6745 kg/kWh for MAB20, MAB30, MAB40 and MAB50 microalgae biodiesel blends respectively. There was deviation of 3.48% to 15.33% in brake specific consumption of fuel for MAB10 to MAB50 in comparison with petro diesel. BSFC declines with the increase in load because for high loads the inside engine cylinder temperature was also high and for such high temperature the fuel viscosity decreases which resulted in appropriate atomization of fuel molecules. Subsequently at high load the engine BP increases and therefore leaded to declined BSFC[34]. Further a minor reduction in BSFC was observed with increased CR because for a higher CR the engine gave reasonably more BP in comparison with an engine running at lower value, henceforth decreased in BSFC[27-29].

3.2 Emissions parameters

3.2.1 Emissions of Oxides of Nitrogen

Conceivably the most basic exhaust emissions from diesel engines were of nitrogen oxides (NOx). The nitrogen oxides (NOx) emissions were exceptionally reliant on combustion chamber temperature,

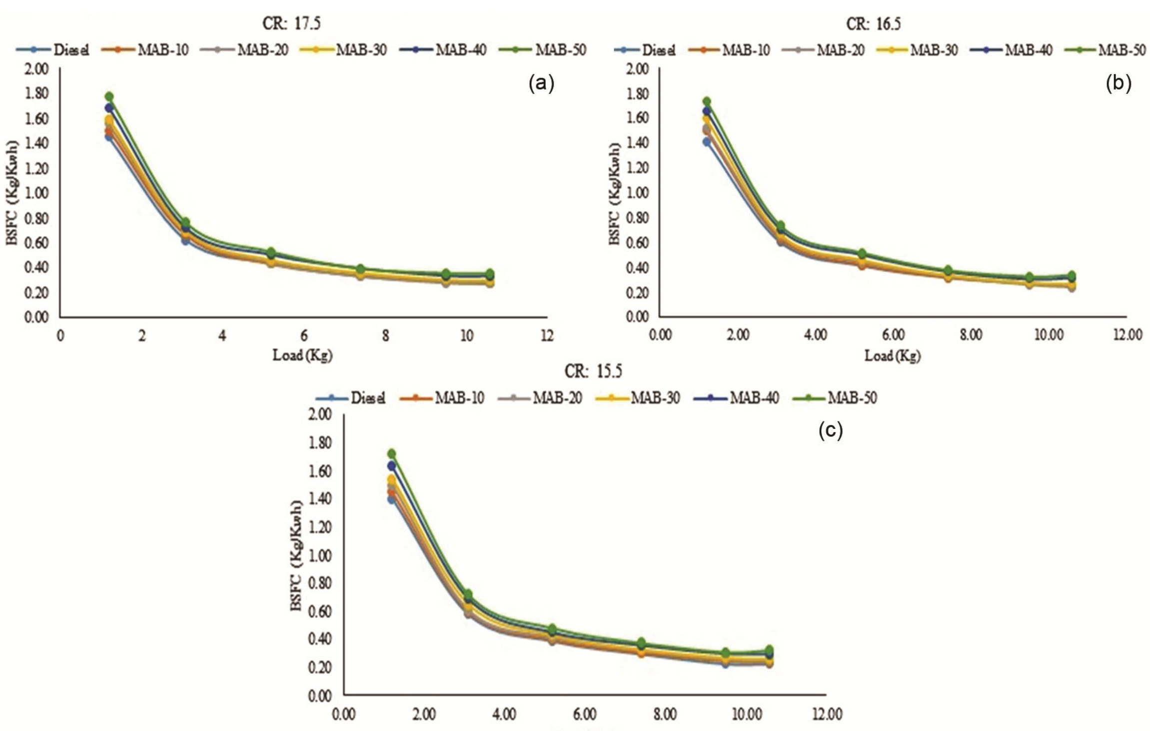

Fig. 8 — BSFC Variation with respect to applied load for (a) CR 17.5, (b) CR 16.5, and (c) CR15.5.

availability of oxygen content and duration required for chemical reaction. Figure 9 (a-c) displayed the variety of NOx emission variations with respect to load applied for three compression ratios 17.5, 16.5 and 15.5 respectively consuming petroleum diesel and five microalgae biodiesel blends. The increase in loading on engine results in increase of nitrogen oxides (NOx). The same trend was also observed for increasing compression ratio because of higher operational temperature. As all the biodiesel oxygen content was higher in comparison with petroleum diesel, there was an increase of nitrogen oxide for all five microalgae biodiesel blends[25, 27-29].

3.2.2 Emissions of Carbon monoxide

Deviation in carbon monoxide exhaust emissions with respect to load applied for three compression ratios 17.5, 16.5 and 15.5 respectively consuming petroleum diesel and five microalgae biodiesel blends were explained in Fig. 10 (a-c). It is observed that emissions of carbon monoxides (CO) for all five microalgae biodiesel blends were less in comparison with petroleum diesel. Fragmentary combustion of injected fuel was the fundamental reason for carbon monoxides (CO) formation because of lack of oxygen or low temperature inside the engine. In case of complete ignition, CO will have got converted to CO_2. Nonetheless, at higher compression ratio, the proportion of CO expands progressively in the engine chamber with escalating temperature. The other factors which favor formation of carbon monoxides fuel's physio chemical properties, A/F ratio (air-fuel ratio), deficiency of oxygen for higher rpm, as well as reduced time accessible for complete ignition[25, 27-29].

3.2.3 Emissions of hydrocarbon

Unburned HC emissions consist of fuel that was incompletely burnt. Figure 11 (a-c) explain the deviation in exhaust emissions of hydrocarbon for applied load with three compression ratios 17.5, 16.5 and 15.5 respectively consuming petroleum diesel and five microalgae biodiesel blends. These figures also narrated that for higher CR the hydrocarbon emissions were less. Furthermore, the amount of no burnt Hydrocarbons (HC) was less for all the microalgae biodiesel blends as compared to petroleum diesel due to greater content of oxygen in microalgae biodiesel. For higher CR, the operational temperature was also higher which enables the complete combustion of fuel and thus minimizes the hydrocarbon in exhaust emissions. As the emissions of hydrocarbon were directly proportional to load applied which may be the significant cause of increase in emissions of hydrocarbons due to more

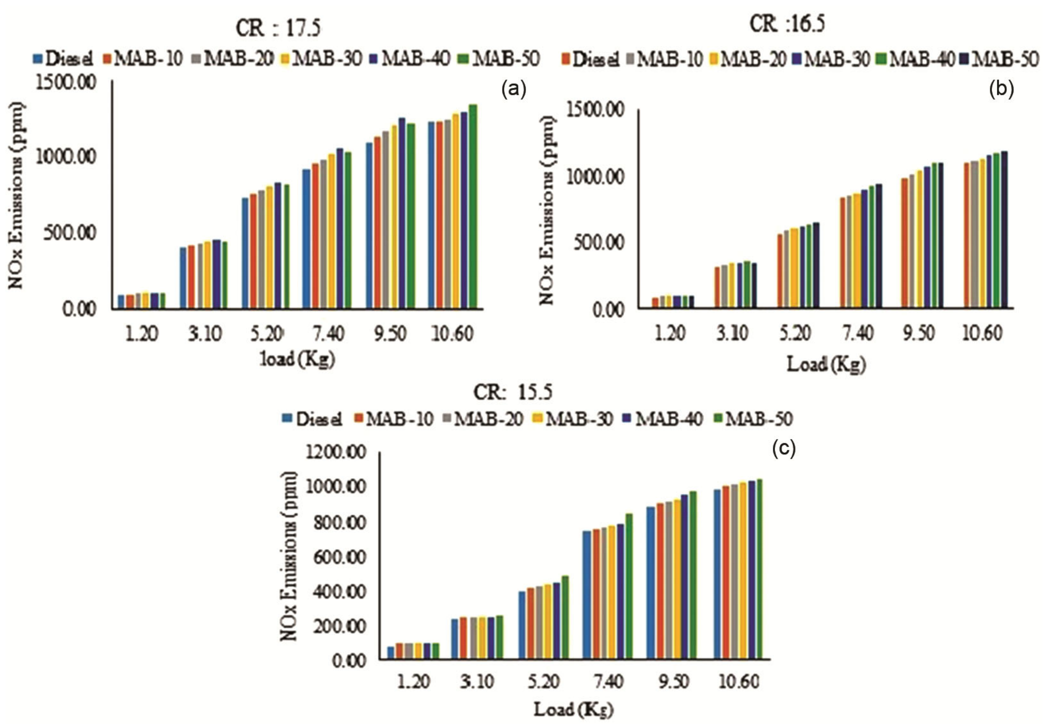

Fig. 9 — Emissions of NOx with respect to load for (a) CR 17.5, (b) CR16.5, and (c) CR 15.5.

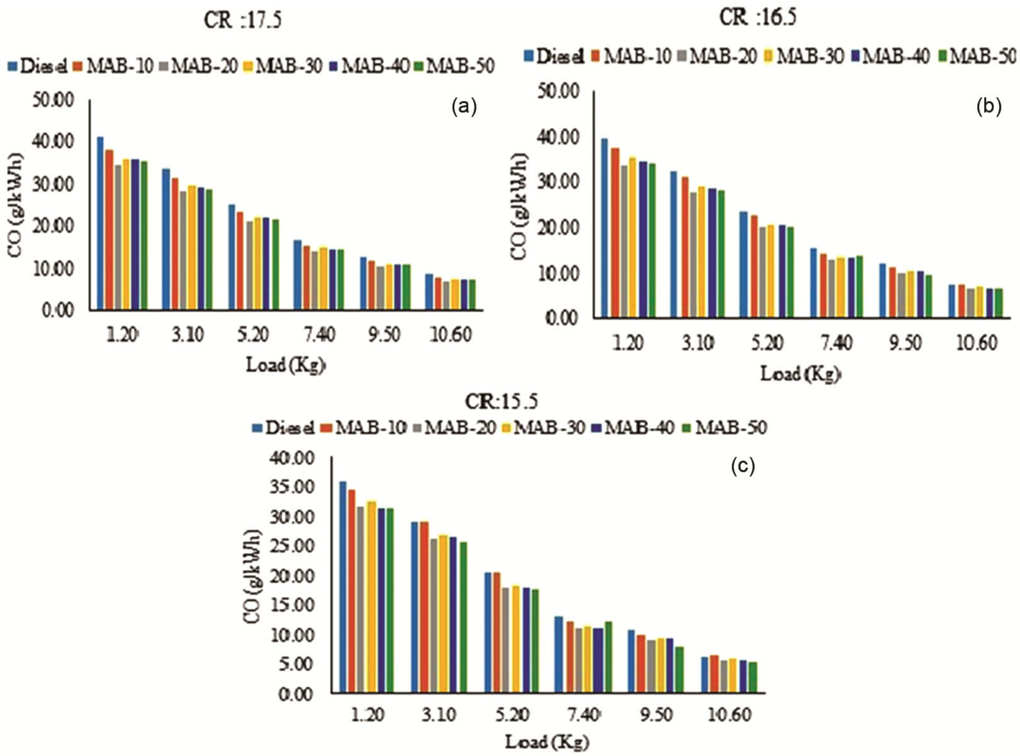

Fig. 10 — Emissions of CO with respect to load for (a) CR 17.5, (b) CR 16.5, and (c) CR 15.5.

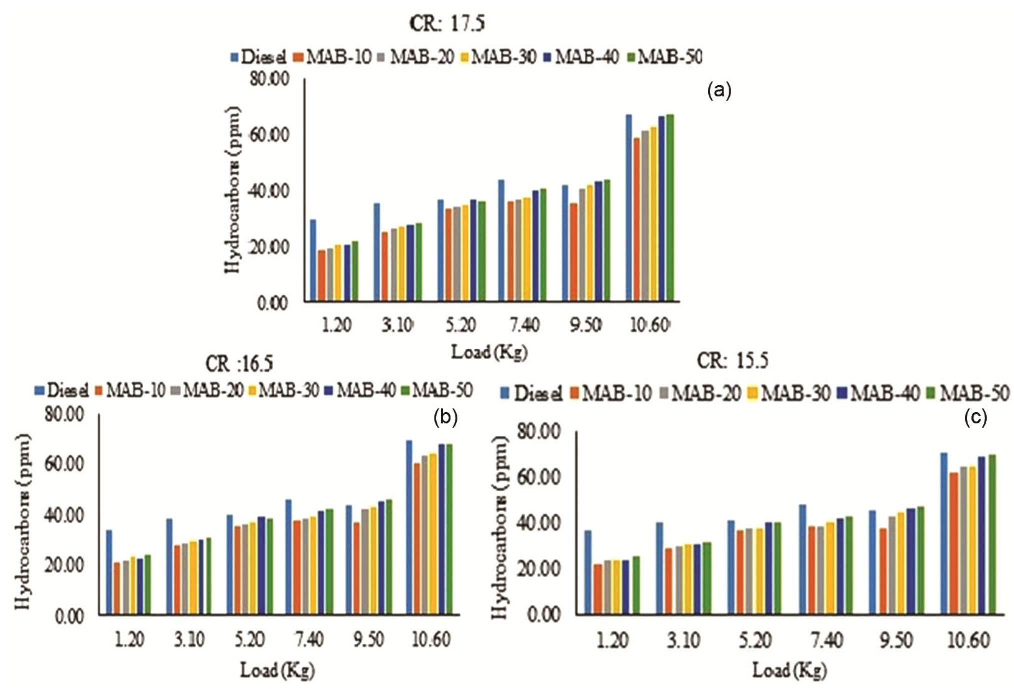

Fig. 11 — Emissions of HC with respect to load for; (a) CR 17.5, (b) CR 16.5, and (c) CR 15.5.

fumigation rate and deficit of oxygen comparable to fuel[25, 27-29].

The results obtained for this experimentation for performance was shown in Figs (7 and 8) whereas the emission results were plotted in Figs (9-11). All these experimental results showed close proximity with the outcomes of cited literature in this experimental study and already published theories which validate the proposed concept of microalgae biodiesel blend use as fuel for CI engine.

4 Conclusion

In this paper, the impact of varying compression ratio on performance as well as emission characteristics of computerized 1- cylinder VCR, CI engine test rig consuming five blends of microalgae has been investigated experimentally. To exhibit its influence these results has been compared with petroleum diesel which leads to major conclusions as;

- The physiochemical properties of all five microalgae biodiesel blends has standard specified by ASTM.
- For the compression ratio 17.5 (Highest CR), the BTE has higher value.
- Preferred stages of combustion has occurred because of premixed charge and which in turn improves the combustion process. The low value of cetane number as well as good vaporization in case of microalgae blends have helped auto ignition at high CR which promotes the fuel efficiency in comparison with diesel[35].
- As the load increases the BSFC has declined, because for high loads the temperature inside engine cylinder was also high and the fuel viscosity decreases with high temperature which appropriates atomization of fuel molecules
- It has observed that for higher CR, emissions of CO and HC has reduced values, which is apparent due to higher content of oxygen in microalgae blends and results in improved mixing rate and combustion.
- As the blending ratio of microalgae increases, the H/C ratio also increases. This hydrogen and carbon radicals attacks the earlier phase flame to form oxides of nitrogen (NOx) at high CR.

Considering the physiochemical properties, performance as well as emission characteristics and influence of varying compression ratio, it has been observed that microalgae biodiesel blend MAB-20 has competitive physiochemical properties, performance and lower emission characteristics. Henceforth microalgae biodiesel blends with 20% of biodiesel and 80% of petro diesel blend at standard temperature and compression ratio 17.5 have gave marginally superior performance and condensed exhaust emission as compared to petroleum diesel.

The impact of microalgae biodiesel blends using nano particles and tubes on performance and emission of VCR CI engine shall be conducted in future because as per literature reviewed nano particles can reduce the NOx emissions.

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