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EXPERIMENTATION STUDIES OF MICROALGAE BIODIESEL BLENDS INFLUENCE ON VARIABLE COMPRESSION RATIO DIESEL ENGINE PERFORMANCE AND EXHAUST EMISSION CHARACTERISTICS

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ABSTRACT

Now a days, the creation of maintainable biofuels from algal biomass has acquired serious consideration and been examined as a possible substitution of petroleum fuel. The utilization of biofuels got from plant biomass in compression ignition engine can lessen a dangerous atmospheric pollutant and different risks on climate (greenhouse gas emission), yet the trouble related to these biodiesel is feed stocks, crop land prerequisite for their cultivation bringing about lack of crop land for growth of food yields. In this situation algae are the finest prominent option of biodiesel. Especially microalgae are most trustworthy resource of biodiesel on the basis that they are non-eatable, and they don't need crop land for their cultivation. This work was directed with an objective to investigate the capability of novel, less considered biodiesel from microalgae species, which can be utilized as a substitute fuel in place of traditional (petroleum) diesel. The biodiesel is extracted by means of transesterification process. On volume basis the microalgae are mixed with petroleum diesel to prepared Microalgae blends (MAB) as per experimentation need. The experimental investigation of impact of biodiesel on performance along with exhaust emission characteristics of single cylinder diesel (compression ignition) engine was researched. Various blends of Microalgae biodiesel presented a reduction in torque and hence brake power resulting in average reduction of 7.14 % in the BTE (brake thermal efficiency) also 11.54 % increase of BSFC (brake specific fuel consumption) as equated to petroleum diesel. With increase in blends ratio in diesel, there were considerable reduction in exhaust emission characteristics which are carbon monoxide (CO), plus hydrocarbon (HC). However, for all the algal biodiesel blends, nitrogen oxides (NOx) and carbon dioxides (CO2) increases but compatible and in acceptable range of petroleum diesel.

KEY WORDS : Algal biodiesel, Fuel properties, VCR compression Ignition Engine, Performance Characteristics, Emission characteristics

INTRODUCTION

The present-day situation of non-renewable energy sources are highly unpredictable and even the world economy relies upon it. Exhaustion of petroleum derivatives with increment in cost rise likewise with disturbing expansion in contamination levels are significant emergency for the general public in this current circumstance. Lots of alternative biodiesel are identified to balance this situation but not claimed full replacement for diesel due to their undesirable physiochemical properties. In Addition

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Nomenclature

MAB10	10% of microalgae biodiesel blended with 90% petroleum diesel
MAB20	20% of microalgae biodiesel blended with 80% petroleum diesel
MAB30	30% of microalgae biodiesel blended with 70% petroleum diesel
MAB40	40% of microalgae biodiesel blended with 60% petroleum diesel
MAB50	50% of microalgae biodiesel blended with 50% petroleum diesel
ASTM	American Society for Testing and Materials standards
FAME	Fatty acid methyl esters
CV	Calorific Value
RPM	Revolution per minute
BP	Brake Power
SFC	Specific fuel consumption
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
HC	Hydrocarbons
NOx	Nitrogen Oxides
CO	Carbon Monoxide
CO_2	Carbon dioxide
VCR	Variable compression Ratio
CR	Compression Ratio

to this an enormous number of vehicles is being offered on the streets consistently. This will increase stress on Petroleum Industries as well as environmental concern. Henceforth it is a need of time for presenting new kinds of alternative fuel to defeat the exhaustion of petroleum products and expansion in contamination (Adesanya *et al.*, 2019).

World Energy 2020 Statistical Review by BP uncovers the accompanying information addressed in the Tables 1a, 1b also 1c, the tables pointed towards a cavity of 4287 thousand barrels per day among oil utilization and its supply for India (BP, 2020). While suggesting better alternative it should also kept in mind that it would not affect mankind food stock. In this concern, from the available edible and non-edible sources of biodiesel it is always desirable to go with non-edible sources because of its advantages.

Table 1b. Production of Oil [1]

	Daily in 2018 (Thousand barrels)	Change over from 2017 to 2018	Total share of 2018
India	869	Minus 1.7 %	0.9%
World	94718	2.4 %	100.0 %

Table 1c. Consumption of Oil [1]

	Daily in 2018 (Thousand barrels)	Change over from 2017 to 2018	Total share of 2018
India	5156	5.9 %	5.2%
World	99843	1.5 %	100.0 %

There are few methods for extraction of biodiesel from available sources, but transesterification is the most widely used and proven chemical process for the same. Transesterification reduces Viscosity Considerably and gives better thermo-physical properties. It is well known fact that biodiesel can be mixed in any proportion with traditional petroleum diesel by volume to get its blends. During experimentation the engine parameters should also be chosen cautiously since they directly influence the performance as well as emission of the engine.

Micro Algae

Different microalgae contain various degrees of oil which proposed its candidature for biodiesel extraction. The major polluting gas carbon dioxide is inspired by algae for its growth. biodiesel creation measure. That is, by methods for photosynthesis, algae devour CO2 (carbon di-oxide) from atmospheric air and supplant that with ambient oxygen. Because of this reason for biodiesel, algal plants are near energy fabricating units which produces loads of CO2 (carbon di-oxide). Reusing CO2 (carbon di-oxide) lessens atmospheric pollution. Besides of this, algae can grow at any place in any atmospheric conditions without disturbing the food crop land acquisition. The oil content makes algae candidature more strong for

Table 1a. Verified existing Oil Assets (Adesanya *et al.*, 2019)

	By the year 2018 end			
	Thousand millions tonnes	Thousand millions barrels	Total Share	R/P Ratio
India	0.6	4.5	0.3 %	14.1
World	244.1	1729.7	100 %	50.0

biodiesel preparation. Amongst thousands of available Algal species, the oil yield per acre land varies from 19000 to 57000 litre per acre.

Algae biodiesel creation (per acre per year) subjected to:

- The kind of algae being utilized
- The way the algae is develop and
- The technique for oil extraction

Competency of Microalgae Biodiesel

For the economically emerging nation like India, microalgae biodiesel will seem, by all accounts, to be attainable answer for defeat petroleum diesel interest. The yearly assessed consumption of petroleum products in India is very nearby to 120 million tonnes every year, and no other feedstock aside from microalgae has the capability to supersede this enormous requirement of petroleum oil need for a yield like soybean or palm to submit sufficient oil able for substitution of petroleum diesel entirely, a colossal level of crop land ought to be used distinctly for biodiesel crop formation from accessible land and this is not feasible sensibly. For small countries like India, it is additionally difficult to commit accessible land just for biodiesel crop development and creation. Considering algae as a biodiesel feedstock which high oil yield per acre, it has been predicted that around 02 to 03 % of absolute crop land of India is adequate for delivering ample algal biodiesel to supplant all petroleum diesel interest of country. Clearly microalgae are predominant elective feedstock for enormous scope biodiesel creation. Comparison of Oil Yield (L/acre) from various sources of biodiesel is given in Figure 1.

METHODOLOGY

Production of Biodiesel from Microalgae

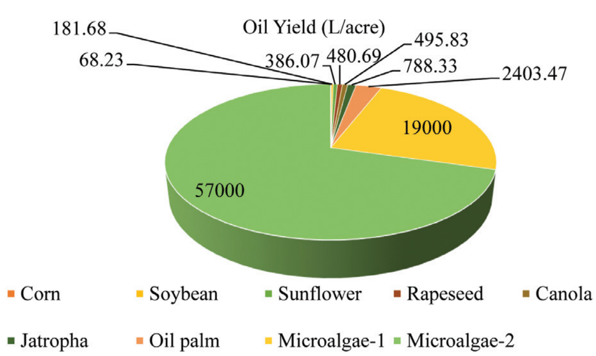


Fig. 1. Oil Yield (L/acre) comparison from various sources of biodiesel

Twenty kilogram of raw Algae sample was taken from outskirts of river at Salai (Mendha) village in Hingna Tahsil of Nagpur district, Maharashtra (Figure 2a). Raw algae were washed clearly (Figure 2b).

After clear washing these algae were grounded in a motor mixer to form possible paste (Figure 2c). The grounded algae paste was dried out at about 80 degrees Celsius for emancipating water by keeping it for at least 20 min (Figure 2d). for extracting oil from algae, solution of Hexane and ether (20ml Hexane + 20 ml ether) were mixed with this dried grounded algae. This compounded mixture was held in reserve for a day (24 hours) to settle down. After settlement the mixture was filtered and biomass was separated properly and measured. Since the collected biomass consists of hexane and ether, it was evaporated in vacuum so as to free from hexane and ether. 0.25 g of NaOH (or KOH) as catalyst was mixed with this extracted methanol and proper stirring is done for half hour (30 min) so as to achieve uniform mixing using magnetic stirrer. Afterword in a conical flask, this mixture of catalyst and methanol was poured into the algal oil. All This processes are carried out as per standard procedure and most popular chemical transesterification reaction is adopted to get good quality microalgae biodiesel.

Using electric shaker, the conical flask containing solution of methanol, catalyst and algae oil was shaken for about 3 hours at 300rpm. In the wake of shaking the arrangement was saved for around 16 hours to settle down the biodiesel and silts the layers unmistakably. The biodiesel was separated from sedimentation by using flagon separator vigilantly. Remaining amount of residue (glycerine, colours, and so forth) were assessed. By using 5% water biodiesel was washed until it was gotten perfect. Biodiesel was dried by utilizing dryer so as to make it water free totally and lastly held under the running fan for 12 hours. Obtained biodiesel was measured and stored safely. Proper Mixing of algae biodiesel with diesel was done on Volume basis as per requirement as shown in Figure 4.

Adopting above methods meticulously the microalgae biodiesel blends MAB10, MAB20, MAB30, MAB40, and MAB50 are prepared as shown in Figure 5.

Properties of Test Fuel

Before going for experimentation, it is very important to know the physical as well as chemical

a. Raw Algae Collection b. Washing of Algae

c. Algae Slurry d. Dried Algae

Fig. 2. Steps in Algae Biodiesel extraction

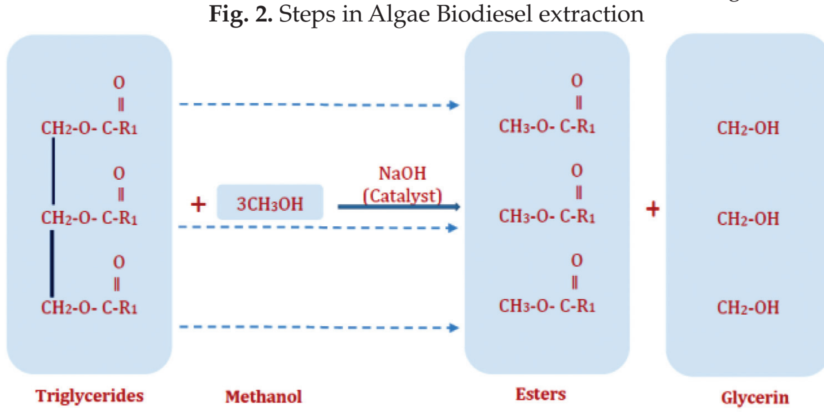


Fig. 3. Transesterification reaction for biodiesel extraction

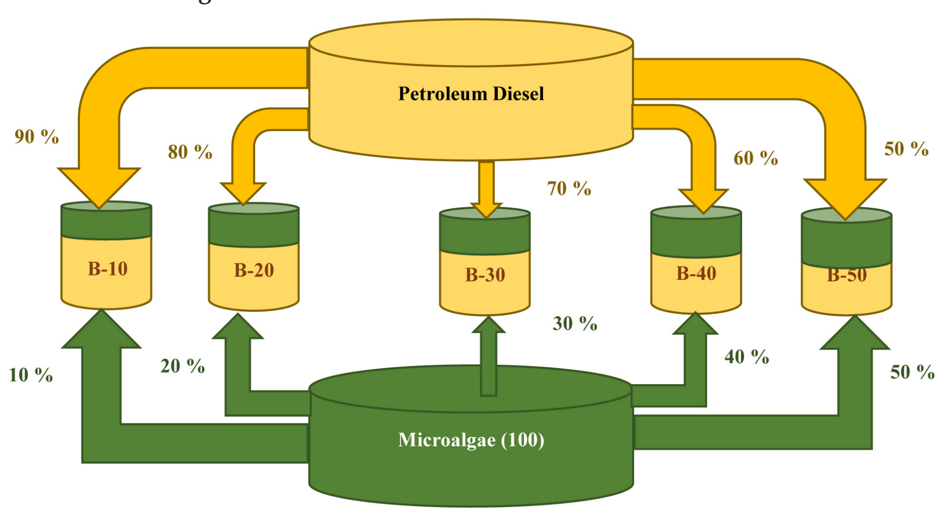


Fig. 4. Biodiesel Blends Preparation on Volume basis

Fig. 5. Actual Algae Biodiesel blends with petroleum diesel

properties of biodiesel and its blend fuel so as to avoid harm to engine. The main properties which should be found out are viscosity, cetane Number, density, flash point, fire point and heating value. The instrumentation done to find these properties are given in Table 2.

Following the ASTM Standard, the chemical and physical properties of teat fuel was find out on laboratory scale at institute. These properties are put forth in Table 3.

Experimental Test Rig

Figure 6 a and b shows the variable compression ratio Compression Ignition Engine test rig situated in thermal engineering laboratory of Institute. The test rig is a single cylinder engine coupled with eddy current dynamometer with facility of varying compression ratio from 12.5:1 to 18:5. The detailed specification are brief in Table 4. All the experiments are carried out as per standard operating procedures.

For observing the emission parameters, MARS Multi Gas analyser (Model: MN-05, ARAI Approved) as shown in Figure 7 is used. The technical specification of Multi Gas analyser is

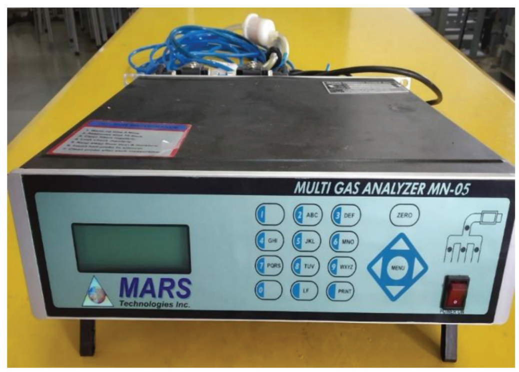


Fig. 7. Multi Gas analyser (MARS, Model: MN-05)

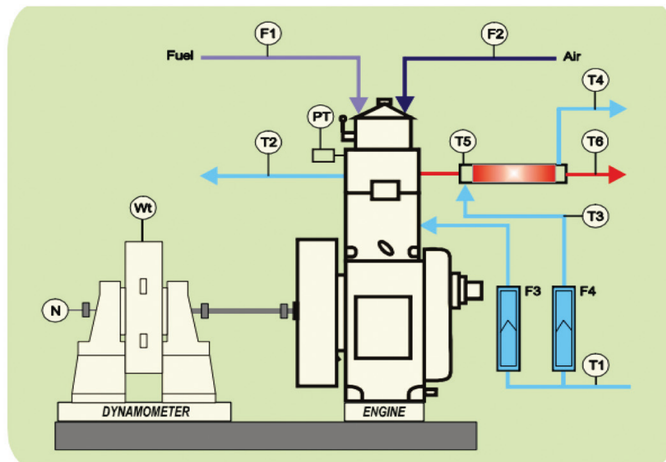
Table 2. Instruments used to find algae biodiesel and its blends properties

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

Table 3. Microalgae Blends chemical and physical properties

Properties	Petroleum diesel	Algae Biodiesel	MAB10	MAB20	MAB30	MAB40	MAB50
Kinematic Viscosity at 104 ^{o}F (mm^2/s)	2.7	3.160	2.746	2.792	2.838	2.884	2.930
Cetane Number	49	48	48.8	48.72	48.66	48.59	48.52
Density @ 150C (kg/m^3)	830	881	835.1	840.2	845.3	850.4	855.5
Flash point (^{o}C)	64	150	72.6	81.2	89.8	98.4	107
Fire point (^{o}C)	71	83	72.2	73.4	74.6	75.8	77
Heating Value (MJ/kg)	42	40.5	41.85	41.83	41.78	41.73	41.69

a. Experimental Test Rig



b. Line Diagram for Experimental Test Rig

Fig. 6. Experimental Test Rig

Table 4. Technical specification of Experimental Test Rig

Parameter	Specification
Model	TV1
Manufacturer	Kirloskar Oil Engines
Form	4-Stroke
Total No. of cylinder	01
Bore Diameter (m)	0.0875
Stroke Length (m)	0.11
Cubic capacity (cm^3)	661
CR	17.5:1
Topmost Pressure	77.5 kg per square cm
Maximum RPM	2000
Minimum idle RPM	750
Minimum. operational RPM	1200
Engines standard fuel timing	230 Before Top Dead Centre
Timing for inlet and exhaust valve :	
Inlet valve opens at	Before Top Dead Centre 4.50
Inlet valve closes at	After Bottom Dead Centre 35.50
Exhaust valve opens at	Before Bottom Dead Centre 35.50
Exhaust valve closes at	After Top Dead Centre 4.50
Cooling System	Water cooling system

provided in Table 5. The measurement range as well as accuracy is also provided in Table 6.

Table 5. Technical Specifications of Multi Gas analyser

Parameter	Specification
OS	PIC- Micro Contoller
Display	LCD Display
Interfacing	RS-232 & RS 485
Power Source	AC- 230Volts, 50Hz , DC -12V (Optional)
Dimensions	450mm X 300mm X 120 mm
Weight	5Kg Approx.
Approval	ARAI, Pune

Before starting the trial on experimental test rig, all the test equipment's were calibrated. Then, one trial run was performed on test rig so that the

Table 6. Measurement Range Resolution of Multi Gas analyser

Parameter	Range	Accuracy
CO	0 to 9.99% Volume	0.001% Volume
CO_2	0 to 20% Volume	0.01% Volume
HC (propane)	0 to 15000 ppm	01 ppm
O_2	0 to 25% Volume.	0.1% Volume
NOx	0 to 5000 ppm	1 ppm Volume
Engine RPM	500 to 6000 rpm	1 rpm
Lambda	0.200 to 2.000%	0.001

operating settings of the experimental test setup should be obtained. After that, the steadiness timing of the experimental test engine rig was made known and the engine was kept for that time for every microalgae biodiesel blend fuels before every experiment. All the minor and major problems (if there any) were resolved in trial run.; after that only, the main experimentation was started. The first experiment was conducted using neat petroleum diesel fuel for minimum 15 minutes so that engine was warmed up.

Performance as well as exhaust emissions parameter was found out for every microalgae biodiesel blends (MAB) with various engine load. Experimentation was carried out on engine in the No-Load Condition using every microalgae biodiesel blends fuel firstly, afterword's frequently applying load in similar range, i.e. 3,6,9,12 and 15 N respectively. The injection pressure was accustomed to achieve the correct results, additionally, inspection of lubrication oil level, air filter, and oil were done and changed if necessary for every new fuel test. To avoid mixing of previous blend with new, the engine test rig ran for a time till the left behind fuel from former tests consumes totally. All the reading was noted after reaching the steady-state condition.

Performance Characteristics

The basic engine performance characteristics such as deviations in fuel consumption, BP (Brake Power), BSFC (Brake Specific Fuel Consumption) and BTE (Brake Thermal Efficiency) in harmony with different engine loads were found out experimentally for the microalgae biodiesel blends and equated it to with petroleum diesel fuel.

Brake Thermal Efficiency (BTE)

The Brake Thermal Efficiency (BTE) for a CI (diesel) engine is a defined as a capacity to develop useful work (Shaft Work) from consumed fuel chemical energy. The BTE versus engine load variation was represented in Figure 8. From the figure it can be clearly stated that, BTE declines with fuel blends type as the load on engine changes and growing as the it increases in comparison with petroleum diesel fuel mode.

Because of less calorific value, as the specific fuel consumption (SFC) increases for microalgae fuel blends mode which obviously decrease the brake thermal efficiency. Further as the blends proportion increases, decrease the calorific value of fuel, this tends in reduction of rate of heat release which finally results in decrease of BTE of the engine (Kalsi and Subramania, 2017; Adesanya *et al.*, 2019).

At standard Compression Ratio, according to experimental results BTE obtained is 32.09% for diesel fuel however 31.32%, 30.87%, 30.49%, 30.10% and 29.80% for MAB10., MAB20. MAB30, MAB40 and MAB50 microalgae biodiesel blends respectively. In total there is reduction observed in case of BTE for MAB10 by 2.41% and MAB50 by 7.14 % in comparison with diesel fuel. As the loading on engine increases, it is observed that BTE also increases, and analogous results trends were attained by earlier researchers in their work. (Elsanusi *et al.*, 2017; Datta and Mandal, 2017; Srihari *et al.*, 2017; Can *et al.*, 2017).

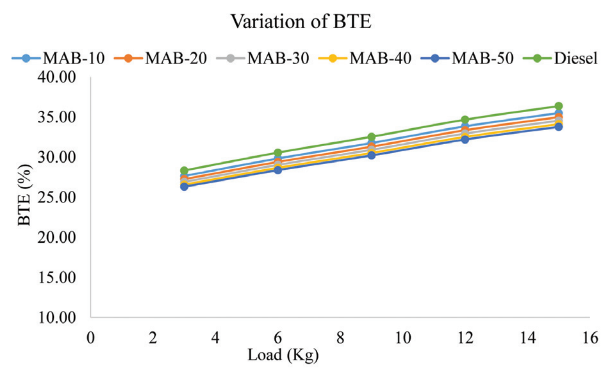


Fig. 8. Brake Thermal Efficiency (BTE) variation with respect to load

Brake specific fuel consumption (BSFC)

The energy (Fuel) amount consumed by engine for giving unit power is termed as Brake Specific Fuel Consumption (BSFC). Brake Specific Fuel Consumption is straight reliant on energy value (Calorific /Heating Value) of the test fuel. The heating value role in complete combustion of fuel is most noteworthy. Since biodiesel and its blends possesses inferior heating value, its direct influence is increase of brake specific fuel consumption values (Celik and Ozgoren, 2017; Celikten *et al.*,]. The behavioural variation in BSFC in accordance to engine ran on different loading is represented in Figure 9. From the plot, it can clearly state that, BSFC is minimum for diesel fuel, trailed by all microalgae biodiesel blends at that loads.

The BSFC (g/kWh) was found to be 294.80 for diesel fuel, 304.91 for MAB10, 308.06 for MAB20, 313.04 for MAB30, 325.16 for MAB40, and 333.27 for MAB50 microalgae biodiesel blends.

The overall increase in the BSFC of MAB10 by 3.43 % and MAB50 by 11.54 % as compared to diesel fuel.

For Each microalgae biodiesel blends, it is observed that BSFC is decreasing with higher load since combustion efficiency increases and this is also being proven from the Fig. 9. The analogous propensity of result is observed in a referred study (Srihari *et al.*, 2017; Can, 2017; Gorji *et al.*, 2017).

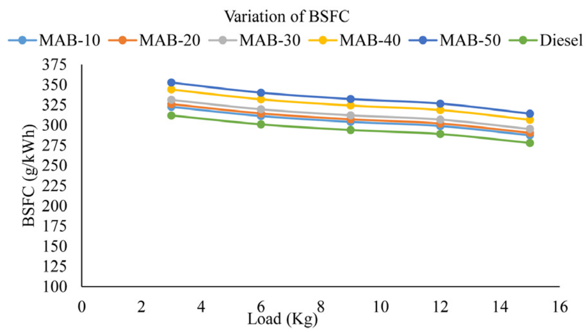


Fig. 9. Brake Specific Fuel Consumption (BSFC) variation with respect to load

Emission Characteristics

Engine exhaust emission characteristics such as CO, CO_2, HC, NOX, emissions in accordance with various loads provided on test engine were found out experimentally in case of microalgae biodiesel blends and equated it with petroleum diesel fuel.

Carbon dioxide (CO_2) exhaust emissions

The CO_2 emissions is one of the key constituents in ozone development. The latest emission laws and regulations rules are restraining the greenhouse gases from various segments of automobile fuels. Viscosity, process of atomization, compression ratio, oxygen, rpm of engine etc. are the factors which influence CO_2 emissions from engine exhaust. Figure 10 depicts CO_2 emissions variation in accordance to engine loading for tested fuel which are petroleum diesel, MAB10, MAB20, MAB30, MAB40, and MAB50. The CO2 was obtained to be higher for microalgae biodiesel blends in comparison with diesel.

The CO_2 exhaust emissions of MAB10 microalgae biodiesel blend are closer to the petroleum diesel. It is observed that carbon dioxide (CO_2) emissions in case of microalgae biodiesel blends was somewhat greater in comparison with same petroleum diesel consumption. From the Figure 10, it can be stated that, CO_2 emission is increasing with increase in blending proportion i.e. From B10 to B50 and decreases with engine load increase. The CO_2 exhaust emissions is 853.96 g/ kWh for petroleum diesel whereas it is 896.47g/kWh for MAB10 microalgae biodiesel blend. There is an increment of 4.74% for B10 microalgae biodiesel blend in CO_2 exhaust emissions, 6.52 % for MAB20, 7.07 % for MAB30, 7.43 for MAB40 and 7.70 % for MAB50 microalgae biodiesel blend. Though the CO2 Emissions were higher but quite compatible with diesel fuel.

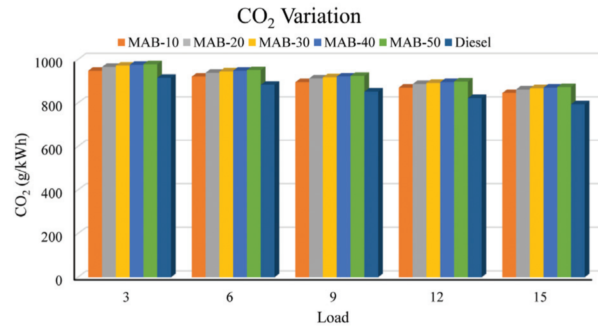


Fig. 10. CO_2 exhaust Emissions Variation with respect to load

Nitrogen oxides (NOX) Exhaust Emissions

Combustion temperature, Oxygen contents of the test fuel and the actual space of combustion zone are the aspects which directly dominates NOX exhaust emissions (Zehra and Orhan, 2015). Some other factors which are responsible for NOX emissions are load on engine, pressure and temperature of combustion, and homogeneousness of biodiesel blends and its density. Stoichiometry, flame temperatures, delay in ignition, composition of fatty acids for fuel, rate of heat removal (HRR), premixing, combustion space, fuel cetane number, injection timing and thermo-physical properties of the fuel are different aspects which influence NOX exhaust emissions (Rajak and Verma *et al.*, 2018; Shrivastava *et al.*, 2019; Verma, 2019). Fig. 15 illustrates the NOX exhaust emission variations for microalgae biodiesel blends and petroleum diesel fuel in accordance with engine loads. It is witnessed that, as the engine load increases, NOX exhaust emission also gradually increases. The average measured values for NOX emissions were 648 ppm for petroleum diesel fuel, 669.77 ppm for MAB10,694.20 ppm for MAB20, 714.09 ppm for MAB30, 741.37 ppm for MAB40, and 722.19 ppm for MAB50.

For Microalgae Biodiesel blends the NOX exhaust emissions were perceived to be larger in comparison with petroleum diesel fuel. This may correlate to the greater content of oxygen level in case of microalgae biodiesel as well as its various blends which increase the combustion gas temperature and results in

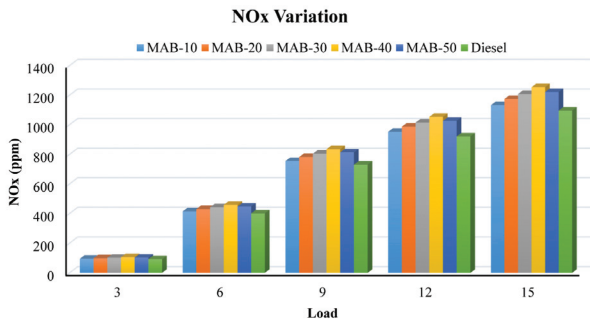


Fig. 11. NOX exhaust emission Variation with respect to load

increasing NOx development by giving surplus oxygen.

Hydrocarbon (HC) Exhaust Emissions

Figure 12 depicts hydrocarbons (HC) exhaust emissions variations for all the microalgae biodiesel blends fuels as well as petroleum diesel in accordance with engine load. The average HC emissions were found as 0.1045 g/kWh in case of petroleum diesel fuel, whereas for MAB10 it is 0.0949 g/kWh, 0.0830 g/kWh for MAB20, 0.0736 g/kWh for MAB30, 0.0796 g/kWh for MAB40, and 0.0909 g/kWh for MAB50 microalgae biodiesel blends. The average reduction in HC emissions with respect to diesel fuel was 9.2% for MAB10, 20.58% for MAB20, 29.62% for MAB30, 23.84% for MAB40, and 13% for MAB50 Microalgae biodiesel blends.

Since microalgae biodiesel contains more oxygen it heightens the oxidation of fuel and hence benefits in of fuel complete combustion, which aids in plummeting HC emissions. Amongst all the Microalgae biodiesel blend, MAB30 have the bottommost average HC emissions but as the blending percentage increase in volume in diesel fuel this increases HC emissions as indicated in Fig. 12. This might be correlated with the greater kinetic viscosity of biodiesel blends, impeding in fuel

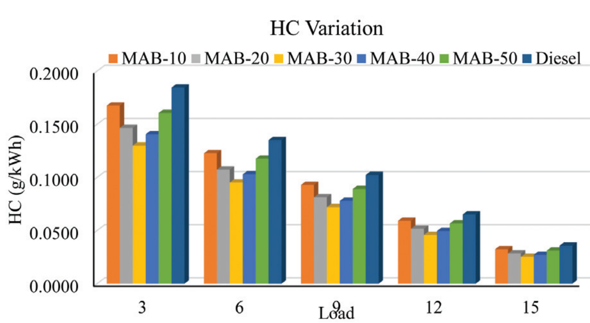


Fig. 12. HC exhaust emission variation with respect to Load

atomization and therefore benefits the HC emissions.

Carbon Monoxides (CO) Exhaust Emissions

Figure 13 illustrates CO exhaust emissions variations for all tested microalgae biodiesel blends and petroleum diesel fuel with respect to the different engine loading conditions. From the observation it is proved that, CO exhaust emission is smallest for greater engine loading for all the fuels tested. Decrease in CO emission as the in engine loading increases which may be correlated to brake power enhancement with increase in engine load.

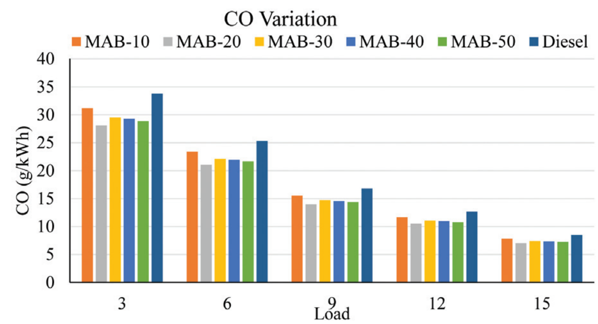


Fig. 13. CO exhaust emission Variation with respect to load

A massive reduction in CO emissions at higher engine load was witnessed for diesel fuel, microalgae Biodiesel blends.

The average CO emissions were found as 19.41 g/kWh for petroleum diesel fuel, 17.92 g/kWh for MAB10, 16.15 g/kWh for MAB20, 16.96 g/kWh for MAB30, 16.83 g/kWh for MAB40 and 16.59 g/kWh for MAB50.

This reduction in CO Emission may explain in linkage with fact that microalgae Biodiesel and its blends are an oxygenated fuel and they have additional oxygen atoms which comforts the complete combustion reaction, thus transforming CO to CO2 molecules, consequently a noteworthy amount of drop in CO emission was observed in case of Biodiesel Blends with diesel.

The overall average reduction in specific CO emission compared to DF was seen to be 7.7% for MAB10, 16.8% for MAB20, 12.60 % for MAB30, 13.30 % for MAB40, and 14.54% for MAB50.

CONCLUSION

biodiesel has been extracted from Microalgae feedstock by following standard operating procedure and materials. The microalgae blends have been prepared by blending it with petroleum diesel in few proportions on volume basis so as to use them as fuel for experimentation. The physiochemical properties of the prepared microalgae biodiesel blends test fuel samples are found to be within limits specified by ASTM D6751. The experimentation was conducted on single cylinder VCR Compression Ignition Engine and the outcomes of experimental investigation are summarized as below:

- In total there is reduction in the BTE of MAB10 by 2.41% and MAB50 by 7.14 % in comparison with petroleum diesel fuel and same trend is observed for MAB20, MAB30 and MAB40 microalgae biodiesel blends.
- BSFC was observed to increase MAB10 by 3.43 % and MAB50 by 11.54 %, with same nature for MAB20, MAB30 and MAB40 microalgae biodiesel blends in comparison with petroleum diesel.
- It is observed that, increment of 4.74% for CO_2 emissions in case of MAB10 microalgae biodiesel blend, 6.52 % for MAB20, 7.07 % for MAB30, 7.43 for MAB40 and 7.70 % for MAB50 microalgae biodiesel blend. Though the CO2 emissions were higher but quite compatible with diesel fuel.
- It is witnessed that, with increase in engine load, NOX exhaust emission also gradually increases. But this problem of higher NOx emission in case of small blends can be handled successfully by using latest technologies such as, little alteration of engine functioning factors and exhaust gas management.
- The average reduction in HC emissions with respect to diesel fuel was 9.2% for MAB10, 20.58% for MAB20, 29.62% for MAB30, 23.84% for MAB40, and 13% for MAB50 Microalgae biodiesel blends.
- The overall average reduction in specific CO emission compared to DF was seen to be 7.7% for MAB10, 16.8% for MAB20, 12.60 % for MAB30, 13.30 % for MAB40, and 14.54% for MAB50.

The aforesaid experimental investigation can be concluded that microalgae biodiesel blend MAB30 has physio chemical properties in close proximity of petroleum diesel in addition to it gives the finest results in terms of performance plus exhaust emission characteristics are concerned. However, to reduce the exhaust emissions parameters the use of prospective nanoparticle or nanotubes in biodiesel blends can be done for further exploration.

Credit authorship contribution statement

Bhojraj N. Kale: Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing - original draft.

Dr. S. D. Patle: Conceptualization, Data curation, Visualization, Project administration, Supervision, Writing – review & editing.

Dr. Nisha Netam: Conceptualization, Data curation, Visualization, Writing - review & editing.

Dr. H.K.Narang: Conceptualization, Data curation, Visualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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