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Effects of Microalgae Biodiesel on Diesel Engine Performance

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ABSTRACT: Environmental concerns are discouraging the use of fossil fuels. Recent studies show promising future for biodiesel as renewable source of energy as a substitute for petro-diesel. As a feed stock for biodiesel, the microalgae have the capacity to provide much higher oil yield than the oilseeds as traditional biodiesel feed stock.
In present study, biodiesel is produced from microalgae (*Schizochytrium* sp.) on laboratory scale with objectives to study the performance and emission characteristics of microalgae biodiesel as a fuel in existing diesel engine. Results show that algae biodiesel can be used in existing diesel engines without modification up to 20% blending with petro-diesel. Reduction in NO_x is seen with 5% blends under part load conditions. Observed higher opacity, higher unburned hydrocarbons and Carbon monoxide with the use of 100% microalgae biodiesel as compared to petro diesel clearly indicate the need for engine modifications for the use of algae biodiesel as fuel.

Key words: microalgae, biodiesel, blending, emissions.

Abbreviations: CO_2, carbon dioxide, CO, carbon monoxide, ASTM, American Society for Testing and Materials, HC, hydrocarbon, rpm, revolutions per minute, mm, millimeter, cc, cubic centimeters, PD, petro-diesel, MB, microalgae biodiesel, kW-h, kilowatt-hour, Kj/Kg, kilo joule per kilogram, ml, milliliter.

I. INTRODUCTION

Global known oil reserves, at the end of 2018 were 1730 billion barrels. The global reserves-to-production ratio shows that known oil reserves in 2018 accounted for 50 years at current rate of production [1]. The rapid increase in the consumption of fossil fuels is resulting into climate change which is considered as the most challenging environmental problem of the present century. Studies indicate that the emission of green house gases to the atmosphere have contributed to the increase in the global mean temperature by approximately 0.8°C during the past century [2]. Rising global temperature is causing abnormal changes in the weather conditions affecting the entire world.
Environmental changes are prompting the world for minimizing the use of fossil fuels and to promote use of renewable fuels. Growing research interests in renewable fuels are evident through enhanced share of renewable in total energy use pattern. In Indian context, a nation with 1.30 billion people and with an annual population growth of 1.2% in last decade [3], the use of energy by transportation sector is rising at the rate of 1.8% every year [4]. Transport sector is the largest energy consuming sector after industrial sector with 27% share of total energy consumption. India is facing growing urbanization resulting due to migrating population from rural areas suffering with inadequate farm earning and civic facilities. This is putting severe pressure on transportation and logistics requirements of urban India. India is also a rapidly growing economy with a GDP growth averaging 7% [5]. Being a growing economy, it is estimated that total diesel demand in India may double by 2030 from 81.1 metric ton in 2017-18 [4]. National biofuel policy 2018 targets 5% blending of biodiesel with petroleum diesel by 2030 [6]. To meet this target, about 8 metric ton biodiesel may be required by 2030. Identified feed-stocks for biodiesel are non-edible oil seeds, used cooking oil and microalgae [6].
Earlier research interests in algae biodiesel [7] were abandoned due to high cost of microalgae oil as compared to crude oil. Cost spikes coupled with depleting crude oil reserves and environmental concerns have caused a renewed focus on the use of biodiesel with microalgae as feed stock. Such research studies attain more significance for a developing nation like India having vulnerable dependency on petro fuel imports to the tune of 80% of its total need [4]. Literature suggests insignificant work on the diesel engine performance evaluation using 100 % microalgae biodiesel with petro-diesel on existing diesel engine without any modifications [8]. A recent work by Abed *et al*., (2019) has reported the effect of different biodiesel fuels on diesel engine emissions including algae biodiesel limited to 20% blending. The present paper focuses on performance evaluation of the microalgae biodiesel up to 100% as a substitute to petro-diesel in existing diesel engine without any modification [9].

A. Using microalgae as a feed-stock
Promotion of jatropha oil seeds as feed-stock under India national biodiesel mission with a target of 20% blending by 2017 failed miserably due to low seeds yield on wasteland [4]. This failure of jatropha oilseeds as major feedstock is resulting in a renewed interest on microalgae as potential feed-stock. As compared to edible or non-edible oil seeds Microalgae are not competing for agriculture land. A high oil content lipid of microalgae has the capacity to provide an oil yield up to 25 times higher than the traditional biodiesel feed stock oil seeds [4]. In Indian context, 0.5% of its geographical area is sufficient enough to meet the present diesel demand.

Furthermore, Microalgae are capable of fixing carbon dioxide (CO_2) from the atmosphere, facilitating the reduction of atmospheric CO_2 levels, which are now considered a global problem. In addition, microalgae biomass production can affect the bio fixation of waste CO_2, reducing emissions of a major green house gas (1 kg of dry algae biomass requires about 1.8 kg of CO_2) [10]. If algae biomass is grown in a sustained way, its combustion has no impact on the CO_2 balance in the atmosphere, because the CO_2 emitted by the burning of biomass is offset by the CO_2 fixed by photosynthesis [11, 12]. Microalgae usually have a higher photosynthetic efficiency than other biomass [13, 14]. A serious thought is required to include microalgae as major feed stock in bio-fuel promotion policy of India. Major identified advantages of microalgae as feed stock are:

– High per unit area productivity.
– Minimized competition with conventional agriculture.
– Utilization of wide variety of water sources.
– Recycles stationary emissions of carbon dioxide.
– Compatible with integrated production of fuels.
– Reduced requirement of petro diesel.
– Net energy ratio of microalgae biodiesel is higher as compared to other biofuels.

Biodiesel, a methyl or ethyl ester of fatty acids, prepared from algae oils is looked upon as potential supplement/alternative to petro diesel. Pure biodiesel can be used in its pure form or in different proportions to form blend with petro diesel. It can be used in diesel engines as it has properties alike to petro diesel as shown in Table 1. Due to lesser sulphur content, biodiesel has self-lubrication property. This causes reduced wear and tear of engine and its components. Biodegradability of methyl ester due to its oxidation leads to lesser damage to flora and fauna in case of accidental spillage. Inbuilt oxygen content of microalgae biodiesel helps in ensuring proper combustion and lesser release of carbon monoxide [8].

II. PREPARING ALGAE BIODIESEL

For engine performance analysis, microalgae biodiesel is produced on laboratory scale. Fig. 1 shows the laboratory setup for the production of microalgae biodiesel.

Fig. 1. Algae biodiesel preparation set up.

In this case, the transesterification process is used to convert microalgae oil (*Schizochytrium* sp.) in to biodiesel fuel. Transesterification of microalgae oil is done with methanol and potassium hydroxide as the catalyst. Methanol is reacted with the algal oil to produce bio-diesel and glycerol. The end products of this reaction are biodiesel, potassium hydroxide methanol and glycerol. The properties of laboratory produced microalgae biodiesel sample are listed and compared with Biodiesel specifications and test methods according to ASTM are compared with those of petroleum diesel in Table 1.

III. EXPERIMENTAL SETUP

The present research work is carried out on 5.2 kW single cylinder four stroke vertical diesel engine test rig shown in Fig. 2. The technical specifications are as listed in Table 2.

Table 1: Fuel properties of microalgae biodiesel fuel compared with petroleum diesel fuel properties [15-17]

Fuel property	ASTM D6751 biodiesel standard	ASTM (D975) Petro diesel	Analysis result of microalgae biodiesel prepared from *Schizochytrium* Sp. oil
Specific gravity @ 15ºC)	0.86 – 0.9	0.85	0.9074
Kinematic viscosity @ 40ºC, mm^2/s	1.9 – 6.0	2.6	3.46
Pour point (ºC)	-15 to 10	20	+3
Cetane number	Min 47	40 - 55	34.4
Calorific Value (Kj/Kg)		42000 - 46000	39200

Fig. 2. Kirloskar TV1 Test Rig.

1. Fly Wheel
2. Coupling
3. Engine
4. Diesel Tank
5. Burette
6. Air Tank
7. Orifice
8. Pressure Differential Meter
9. Exhaust gas outlet
10. Air Surge Tank
11. Base

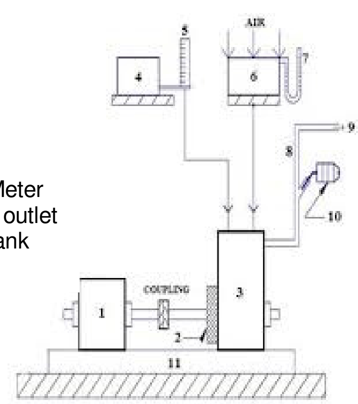

Fig. 3. Line Diagram of Kirloskar TV1 Test Rig.

Table 2: Specification of Engine (Kirloskar Model T – VI).

Engine Parameters	Details
Make and model	Kirloskar, Model T - VI
Type of engine	Single Cylinder, 4 Stroke, Diesel Engine Test Rig
No of cylinder	Single Cylinder
Rating @ 1500 rpm	1500 RPM
Type of cooling	Water cooled
Rated power output	7 BHP, 5.2 kW
Bore & Stroke	Bore 80 mm, Stroke 110 mm,
Swept volume	661 cc
Clearance volume	38.35 cc
Compression ratio	17.5
Nozzle opening pressure	210 bar
Fuel injection timing	23° BTDC
Burette range	0 – 50 ml
Dynamometer type	Brake rope dynamometer, water cooled

IV. SETUP FOR EMISSIONS MEASUREMENT

The combustion products from diesel engine exhausts are grouped into two parts, one is exhaust smoke and the other is the remaining emissions. The exhaust emission gases namely CO, CO_2, HC, O_2, and NO_x were analyzed using gas analyzer (model AVL DiGas 444). Opacity and smoke temperature were analyzed using AVL 437L Smoke Meter approved from Automotive Research Association of India. The specifications and calibration data of the gas analyzer are listed in Table 3 and 4.

Table 3: AVL exhaust gas analyzer model AVL DiGAS 444N.

S. No.	Discription	CO (%)	HC (ppm)	CO_2 (%)
1.	STD. Gas Bottle	3.52	2030	14.03
2.	Acceptance Criteria	$\pm$ 0.10	$\pm$ 102	$\pm$ 0.56
3.	Observed Value	3.53	2022	14.04
4.	Result	OK	OK	OK

Table 4: AVL 437C Smoke Meter.

S. No.	Particulars	Measurement Range	Resolution
1.	Opacity	0........100%	0.1%
2.	Absorption (K value)	0.........99.99%	0.01m-1
3.	Engine speed (RPM)	4000......6000 min-1	1 rpm
4.	Oil temperature	0........150°C	1°C
5.	Linearity check	=50% of measurement range	

Fig. 4. AVL exhaust gas analyzer model Avl digas 444n.

Fig. 5. AVL 437c Smoke Meter.

V. EXPERIMENTAL PROCEDURE

The line diagram of experiment setup is shown in Fig. 3. The engine and the dynamometer are coupled by using general flexible type coupling. Initially the engine is run with diesel fuel at zero load condition. The tests on base line engine are conducted by maintaining the constant speed of 1500 RPM by varying the loads. When the engine gets steady condition under different loads, the output parameters are recorded. The experiments are conducted at different load conditions i.e.0 kg, 2 kg, 4 kg, 6 kg, 8 kg, and 10 kg.

At each load, the measurements of intake air, fuel consumption, intake air temperature, exhaust gas temperature, engine coolant temperature, air fuel ratio, un-burnt hydrocarbon (UHC) emission, carbon monoxide (CO) emission, nitrogen oxides (NO_x) emission and smoke opacity are recorded.

VI. RESULTS AND DISCUSSIONS

Obtained experimental results are presented in graphical form in Fig. 6-13. The performance and emission characteristics of 100% petro-diesel, 100% microalgae biodiesel, 5% and 20% blend of microalgae biodiesel with petro-diesel are discussed in this section.

A. Analysis of brake specific fuel consumption (BSFC)
Fig. 6 shows the observations of BSFC with Load. It is observed that BSFC is decreasing with increasing load. BSFC mainly depends upon the relationship between fuel density, viscosity and energy content. Higher BSFC with biodiesel at lower loads can be attributed to lower calorific value of biodiesel as compared to petro-diesel. At higher loads, BSFC is comparable with 100% and 20% blend of biodiesel. For 5% blend, BSFC is comparable with 100% petro-diesel. At 100% biodiesel & 20% blending of biodiesel, BSFC is higher at lower and medium load condition; it is lower at higher load condition. Higher oxygen content results in better combustion of biodiesel thus compensating for lower calorific value of biodiesel. Compare to the biodiesel blends, petro diesel shows less BSFC under all load conditions due to its high heating value and low density.

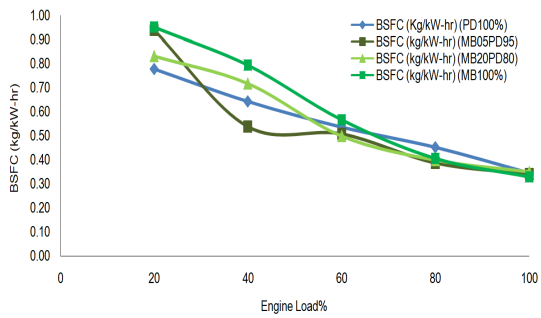

Fig. 6. BSFC (kg/kW-hr) V/s Engine load % for petro diesel 100%, algae biodiesel 100% and blends of petro diesel + algae biodiesel (MB05PD95 & MB20PD80).

B. Analysis of brake thermal efficiency (BTE)
Fig. 7 shows the variation of BTE with load. In general, BTE is increasing with increasing brake load. It is observed that while using 100% biodiesel as compared to 100% petro diesel, the value of BTE is higher. The BTE with 5% blending is comparable with petro diesel under all load conditions. Lower BTE with biodiesel blends at lower loads can be attributed to lower calorific value of biodiesel. At higher loads, biodiesel gives better efficiency as compared to petro diesel due to better combustions resulting from associated oxygen. For 20% blend observed BTE is highest at rated load thus indicating the optimal blending limit for existing diesel engine.

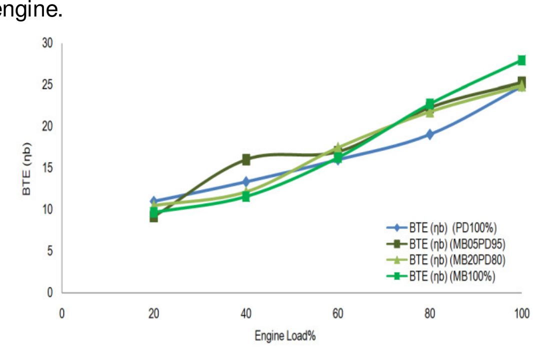

Fig. 7. BTE ((ηb) V/s Engine load% for petro diesel 100%, algae biodiesel 100% and blending of petro diesel + algae biodiesel (MB05PD95 & MB20PD80)).

C. Emission analysis of NO_x
Fig. 8 illustrates the variation of NO_x with load. It is observed that with 100% biodiesel as compared to 100% petro diesel the observed value of NO_x concentration is less at lower load conditions and more at higher load conditions. For 20% blend, NO_x emissions are comparable at lower load and are higher under mid-load range. Under full load conditions, lower NO_x emissions are observed with 100% biodiesel and also with 20% biodiesel blend as compared to petro diesel. For 5% biodiesel blend, the observed NO_x is higher at lower load as well as at higher load conditions. Although a reduction in NO_x can be observed at middle load range. Higher heat generation at higher load, resulting in higher temperature in the combustion chamber, is major reason for increased NO_x emissions.

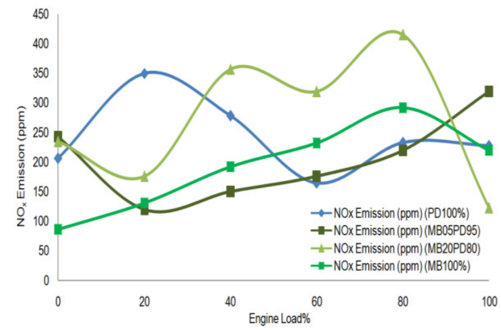

Fig. 8. NO_x Emission (%) V/s Engine load % for petro diesel 100%, algae biodiesel 100% and blending of petro diesel + algae biodiesel (MB05PD95 & MB20PD80).

Associated oxygen of microalgae biodiesel further helps in NO_x formation. Higher NO_x has been reported with blends of biodiesel by other researchers also [8, 9, 18]. For 5% blend of microalgae biodiesel, NO_x is lower as compared to petro-diesel under part load conditions.

D. Emission analysis of CO_2
Fig. 9 depicts the variation of CO_2 with load. It is observed that with 100% biodiesel, as compared to 100% petro diesel, the concentration of CO_2 is higher under all load conditions, except under no load condition, resulting from higher amount of fuel combustion due to lower specific heat of biodiesel. For 20% blend, lower CO_2 is observed under full load condition and same is consistent with the findings of other reported work [19].
At higher load conditions, CO_2 emission is higher for microalgae biodiesel. The major reason is higher fuel consumption due to low calorific value of biodiesel. For 5% blend of microalgae biodiesel at part load conditions, the value of CO_2 is lower as compared to petro-diesel. For this blend, under part load conditions, lower specific fuel consumption is observed and hence resulting lower CO_2 emissions.

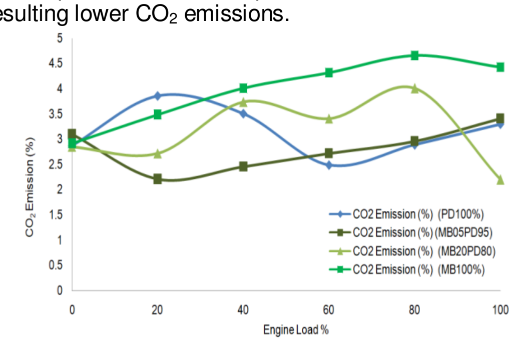

Fig. 9. CO_2 Emission (%) V/s Engine load % for petro diesel 100%, algae biodiesel 100% and blending of petro diesel + algae biodiesel (MB05PD95 & MB20PD80).

E. Emission analysis of CO

The variation of CO (carbon monoxide) with load is shown in Fig. 10. It is observed that with 100% biodiesel as compare to 100% petro diesel the concentration of CO is higher under all load conditions. The values of CO emissions at full load are lower for 5% & 20% blends with petro diesel. The major reason for reduction of CO is more complete combustion due to associated oxygen with biodiesel [8, 9, 19]. With 100% biodiesel, significant increase in CO emission can be observed. This clearly indicates the need for engine modifications requirement for 100% algae biodiesel.

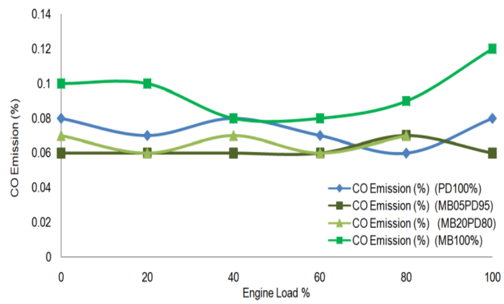

Fig. 10. CO Emission (%) V/s Engine load% for petro diesel 100%, algae biodiesel 100% and blending of petro diesel + algae biodiesel (MB05PD95 & MB20PD80) biodiesel.

F. Emission analysis of unburned hydrocarbons (HC)

Fig. 11 shows the observations of HC with load. It is observed that with 100% biodiesel as compared to 100% petroleum diesel, the value of unburned HC is lower at lower load conditions and higher at higher load conditions. For 5% blend, it is lower at all load conditions and for 20% blend it is higher at higher load conditions comparable in mid and lower at higher loads.

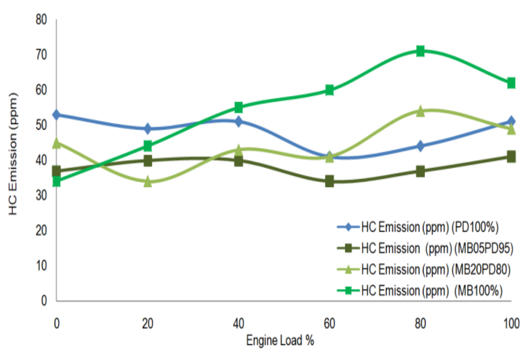

Fig. 11. HC Emission (ppm) V/s Engine load% for petro diesel 100%, algae biodiesel 100% and blending of petro diesel + algae biodiesel (MB05PD95 & MB20PD80) biodiesel.

Unburned hydrocarbons emissions are result of incomplete combustion. Improper atomization due to density difference of petro diesel and biodiesel is one possible reason for incomplete combustion. At part load conditions, associated oxygen with biodiesel compensates for improper atomization thus a comparable HC emission may be observed. In present case study, Lower cetane number of biodiesel appears to be major reason for significantly higher HC for 100% biodiesel case. Presence of higher unburned HC clearly indicates the need of engine modification with 100% biodiesel.

G. Emission analysis of Opacity

Fig. 12 shows the observations of opacity with varying load. It is observed that with 100% biodiesel and 20% blend of biodiesel as compare to 100% petroleum diesel the value of unburned opacity is lower at lower load conditions, and for 100% biodiesel it is higher at higher load conditions for 5% blend of biodiesel it is comparable with 100% petro diesel and for 20% blend the unburned opacity is lower at medium load condition, little bit higher at medium higher and again lower at higher load condition. Smoke opacity is the particulate matter resulting from partially burning of the fuel due to poor atomization of high viscous fuels.

For 20% blend, opacity is lower except under 80% load condition. The increase of smoke emission with increase in engine load is due to increase in fuel consumption which led to rich air-fuel mixture. Similar results were obtained by reference [8, 9].

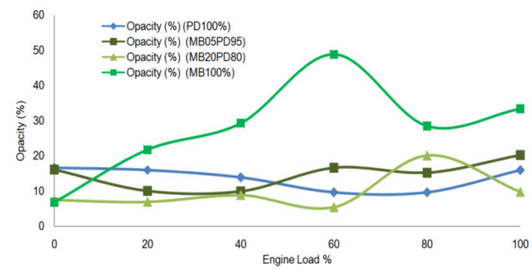

Fig. 12. Opacity (%) V/s Engine load% for petro diesel 100%, algae biodiesel 100% and blending of petro diesel + algae biodiesel (MB05PD95 & MB20PD80) biodiesel.

H. Exhaust Smoke Temperature

Fig. 13 shows the observations of exhaust smoke temperature (℃) with varying load. It is observed that with 100% biodiesel and 20% blend of biodiesel as compare to 100% petroleum diesel the value of exhaust smoke temperature is comparable at lower load conditions and lower at higher load conditions. For 5% blend the exhaust temperature is comparable. Exhaust temperature is an important feature which should be kept in account as any increase of it affects the temperature of the surrounding environment. This may exert good or bad effect on the flora or fauna of that habitat. Exhaust temperature also gives an idea of the temperature inside the engine, and engine temperature plays a very important role in emission of different gases. Similar results were obtained by reference [8, 9].

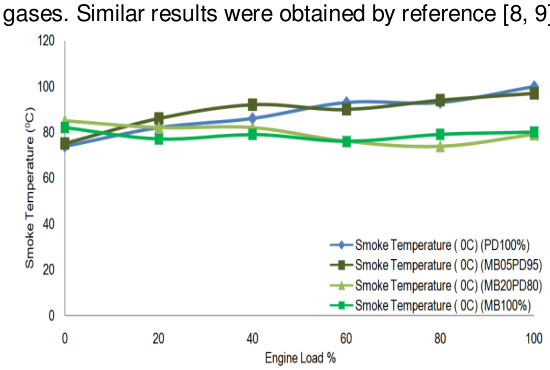

Fig. 13. Smoke Temperature (ºC) V/s Engine load% for petro diesel 100%, algae biodiesel 100% and blending of petro diesel + algae biodiesel (MB05PD95 & MB20PD80) biodiesel.

VII. CONCLUSIONS

Environmental concerns are one of the major forces for the use of renewable fuels and for discouraging the use of fossil fuels. Recent studies show promising future for biodiesel as sustainable renewable source of energy as an alternative to petro diesel.

As a feedstock for biodiesel, the microalgae have the capacity to provide much higher oil yield than the traditional biodiesel feedstock oilseeds. Microalgae are capable of fixing CO_2 in the atmosphere thus facilitating the reduction of CO_2 levels.

To evaluate the performance of microalgae biodiesel and its blends with petro-diesel on existing diesel engine, microalgae biodiesel is prepared from *Schizochytrium* sp on laboratory scale. Measured physical and chemical properties of prepared biodiesel are comparable with petro-diesel. To study the performance and emission characteristics of microalgae biodiesel as a fuel in existing diesel engine, this study is carried out on 5.2 kW single cylinder four stroke vertical diesel engine test rig. Results show higher brake specific fuel consumption with biodiesel at lower loads and same may be attributed to lower calorific value of biodiesel. At higher loads, it becomes comparable to petro-diesel due to higher associated oxygen of microalgae biodiesel resulting in better combustion. For 5% blending case, no significant variation is being observed for measured parameters. Reduction in NO_x at part load conditions is a positive indicator for supporting present Indian biofuel policy recommending 5% blending. For B20D80 blend, observed BTE is highest at rated load thus indicating the 20% microalgae biodiesel as optimal blending limit for existing diesel engine. The value of exhaust CO is also lower with blending of 20% algae biodiesel under low load conditions and is comparable for higher load conditions. At part load, lower unburned hydrocarbons and lower opacity are observed with 20% blend. Comparable NO_x concentration, at rated load, in exhaust emissions further justifies 20% blend. Higher opacity, unburned hydrocarbon and CO with 100% biodiesel clearly indicate the need for engine modifications. Thus, promotion of microalgae biodiesel for 20% blending in existing diesel engines may be taken up under long term bio-fuel policy. Future research should focus on engine modifications and optimization for developing a dedicated engine for strain specific algae biodiesel.

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Conflict of Interest. The authors declare no conflict of interest associated with this work.

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