



Spectroscopic Performance and Emission Analysis of *Glycine max* Biodiesel

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Abstract Biodiesel is an alternative, clean and green fuel because of its non-toxic, biodegradable properties. The rationale behind this research is to examine the efficiency of biodiesel extracted from *Glycine max* oil by means of the heterogeneous catalyst method. The biodiesel was blended with mineral diesel at different percentages (%), before being applied to test the engine performance as a source of fuel. Variations of carbon monoxide, brake thermal efficiency, hydrocarbon, exhaust gas temperature, brake specific fuel consumption, NO_x and brake thermal efficiency versus load for fuels were performed. At lower load BSFC and BTE of biodiesel are almost similar to diesel. The emission of CO and HC reduce appreciably as a result of biodiesel. It was obtained that at full load condition, there was a 2.38%, 4.76%, 7.61% and 10% reduction in CO emission, with B5, B10, B15 and B20, respectively. The characterization was also done by using spectroscopy like UV–Vis and Fourier transform infrared. The characteristic of diesel and fatty acid profile was observed at 1745/cm, showing the existence of strong ester carbonyl bond (C=O) indicating the presence of fatty acid methyl ester or biodiesel in FTIR. The variable concentration of blending was established by UV–Vis absorption spectra. The linearity of absorbance declined and linear line fitted for absorbance versus the percentage of biodiesel at 320 nm showed a high coefficient of determination ($R^2 = 0.9651$).

Keywords Glycine max biodiesel · Brake specific fuel consumption · FTIR · Brake thermal efficiency · UV–Vis spectroscopy · Engine performance · Engine emissions

Introduction

The increasing worldwide demand in energy production led to the reduction in use of fossil fuels and sustainable harness of biodiesel. Biodiesel is fatty acid esters, which may be obtained either from animal fat or vegetable.

During storage, biodiesel undergoes oxidative degradation due to the presence of reactive allylic and bisallylic sites. Oxidation stability is fuels reaction with oxygen at ambient temperature [1]. The degradation would lead to the development of unwanted products, which may affect the properties of biodiesel and also the performance of the engine [2]. The parameters like acid value and viscosity remain unchanged. The major change occur during storage is the peroxide value, measuring hydroperoxides, which decomposes to ketones, acids, etc. [3]. Saifuddin and Refal indicated that higher proportionate of polyunsaturated organic fuels is more reactive in terms of oxidation than monounsaturated, which are unstable [4]. Biodiesel produced from a broad range of feedstock varies in their characteristics. The production of biodiesel is also determined by thin layer chromatography [5]. The different methods like infrared spectroscopy, nuclear magnetic resonance (NMR) and chromatography are used to determine the content of biodiesel [6]. NMR is no doubt outstanding method, but it is costly in indicating biodiesel content with high coefficients of correlations [7]. FTIR technique is employed for examining oxidative degradation of

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biodiesel, which has their characteristic absorption in the region of 1745 per cm attributable to the presence of ester carbonyl group.

The attendance of conjugates in the oxidized biodiesel may be determined by UV–Vis spectroscopy. Vega-Lizama et al. [8] indicated that at a specific wavelength, a positive linear correlation existed between the peroxide value and the UV absorbance.

UV–Vis spectroscopy determines the content of heptanes-diluted biodiesel and diesel-blended concentration intervals. Zawadzki et al. [9] indicated two intensive absorption bands along 230–260 nm wavelengths. Nevertheless, UV–Vis spectroscopy provides faster results because of less time in analysis and also less reagent consumption.

Biodiesel has an advantage of lower emission rate and clean fuel [10, 11]. The main issue with biodiesel is it contains a lower energy rate and higher emission of NO_x as compared to diesel. To overcome this issue various additives are added in biodiesel [12, 13]. The use of vegetable oil directly in the engine is prohibited as it leads to improper combustion, improper atomization, carbon deposition and injector chocking. This issue occurred, because the oil contained higher viscosity [14]. However, many advantages are there in using biodiesel such as it can be easily linked with the application of diesel engine with very low modification. It is also eco-friendly in nature and contains lower harmful substances. Biodiesel is also feasible at various blending rates with diesel [15]. Many researchers have found that the emission rates of HC, CO, smoke and CO_2 were reduced up to maximum limit by the use of biodiesel. However, the emission rate of NO_x increases with the increase in the percentage usage of biodiesel [16, 17]. The main reason behind the enhancement of the rate of NO_x emissions is relative stoichiometry, aromatic content, heating value and biodiesel composition. The rate of production of NO_x increases with the use of methyl soyate in the blend, and it varies from 3–19% to 10–100% blend, respectively. At full load condition (B100), the rate of NO_x can be decreased by 4% (approx.) by reducing the heat obtained by exhaust temperature. The reduction in PM, HC and CO in biodiesel takes place due to advance combustion time (ACT), enhanced oxygen content, enhanced biodiesel saturation and higher rate of CN. This reduction was evaluated in comparison to diesel fossil fuel. The rate of reduction in emission of CO varies in the range of 7–42% with an increase in the rate of concentration of methyl soyate ranging from 10 to 100% [15–17].

In this paper, vegetable oil derived fuels produced from *Glycine max* is characterized by FTIR and UV–Vis spectroscopic method. The result would form the basis for

controlling emission, performance and also optimization of the fuel.

Sample Preparation

Production of *Glycine max* Biodiesel

(a) Procurement of Oil

Glycine oil was purchased from the Ghaziabad market, U.P., India. The oil was filtered, and the filtered oil was trans-esterified.

(b) Transesterification of *Glycine* Oil

The filtered oil was heated on magnetic stirrer until the temperature of the oil reaches 60 °C. Methanol and heterogeneous catalyst Al_2O_3 (98%, Sigma Aldrich) were added to it. The heterogeneous catalyst Al_2O_3 was used for increasing the yield of biodiesel. It was trans-esterified for 1 h on magnetic stirrer at 1700 rpm around 60–65 °C (Fig. 1).

(c) Separation of Biodiesel

After transesterification, the produced biodiesel was kept at separating funnel for 24 h. The biodiesel being lighter settles at the top and glycerine at the bottom. The biodiesel collected is washed by means of distilled water 2–3 times to eliminate the glycerine. Washing of the biodiesel with distilled water turns milky, indicating the presence of traces of glycerine. The washed biodiesel was kept on the magnetic stirrer until the temperature of biodiesel reaches 100 °C. It is kept till the time until the first bubbles appear. The purpose of drying is to evaporate traces of distil water present on biodiesel.

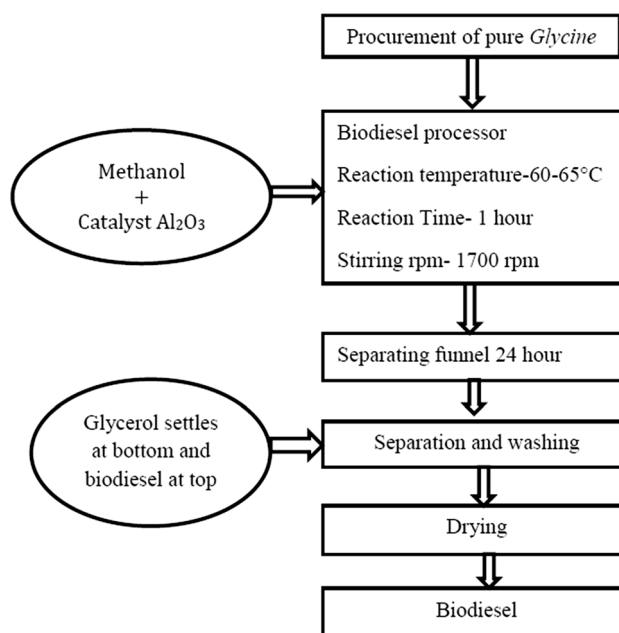


Fig. 1 Flowchart of biodiesel production from *Glycine max*

(d) Sample Preparation

Fuel samples containing B5 (5% *Glycine max* biodiesel and 95% Pure Diesel), B10 (10% *Glycine max* biodiesel and 90% Pure Diesel), B15 (15% *Glycine max* biodiesel and 85% Pure Diesel) and B20 (20% *Glycine max* biodiesel and 80% Pure Diesel) of *Glycine max* biodiesel in diesel oil were used in the tests. Table 1 shows the physical and chemical properties of the base diesel oil, ASTM standard and pure biodiesel (B100).

Experimental Setup

The performance was studied on a 5BHP single-cylinder four-stroke, direct-injection water-cooled diesel engine using diesel blends with glycimax biodiesel (B5, B10, B5 and B20) by varying the engine load (%) at constant speed 1500 rpm (Fig. 2). Details of the engine specification of the proposed engine are given in Table 2. AVL Di-Gas Analyzer was used to measure the exhausts gas of the engine. The inlet manifold of the analyzer is connected to the exhaust valve of the engine so that the emissions can be measured.

Results and Discussion

Fourier Transform Infrared Spectroscopy (FTIR) Studies of Biodiesel

Characterization of *Glycine max* biodiesel for functional group determination was carried out by means of FTIR. This provides a mechanism of spectral changes ensuing from the reaction. Biodiesel spectrum patterns (5, 10, 15 and 20%) fall between the 500 and 3450/cm spectral range. *Glycine max* biodiesel infrared spectrum showed the triglyceride ester linkage at 1745/cm. The spectrum ranging from 725 to 1161/cm is for aromatic hydrocarbon, whereas 1160–1234/cm is for carbon–oxygen bond absorption (C–O bonds absorption) [18]. The absorption at



Fig. 2 Pictorial view of the setup

Table 2 Engine specifications

Make and model	Kirloskar, TV1
Engine type	4 stroke
Number of cylinders	Single cylinder
Cooling media	Water cooled
Rated capacity	5BHP at 1500 rpm
Cylinder diameter (mm)	87.5
Stroke length (mm)	110
Connecting rod length (mm)	234
Compression ratio (<i>r</i>)	17.5
Dynamometer	Eddy current dynamometer

1373/cm designates the methyl group (CH₃), whereas the peak at 1458/cm is indicated as the bending absorption of CH₂. The peak at 1600/cm is missing in *Glycine max* biodiesel, where as it is present in all blended biodiesel as well as diesel. This indicates C=O signal area, absence of methyl in biodiesel diesel blends in *Glycine max* biodiesel.

Table 1 Physical–chemical properties of the diesel oil, pure biodiesel (B100)

Properties	Test method	Diesel	<i>Glycine max</i> biodiesel (soya)
Density (kg/m ³)	ASTM D1298	810.26	872.12
Viscosity (centistoke)	ASTM D445	3.18	4.78
Calorific value (MJ/KJ)	ASTM D240	42.5	34.69
Flash point (°C)	ASTM D93	51	98
Fire point (°C)	ASTM D93	56	103
Pour point (°C)	ASTM D97	– 20	– 4
Cloud point (°C)	ASTM D97	– 5	12
Cetane number	–	54	47

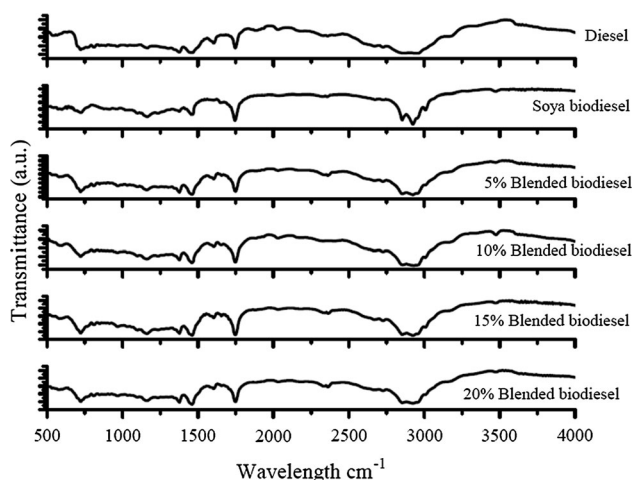


Fig. 3 FTIR of diesel, *Glycine max* biodiesel and 5%, 10%, 15% and 20% blended biodiesel

Again, the peak around 1886/cm is present in diesel, which is shifted to 1882–1878/cm in 5% and 10% blended biodiesel, respectively.

A peak at 1747.51/cm (5%), 1747.47/cm (10%), 1747.36 (15%) and 1751.36/cm (20% blended biodiesel) showed the occurrence of strong ester carbonyl bond (C=O), thus proving the presence of fatty acid methyl ester (FAME) or biodiesel. At higher blends of biodiesel, this peak is absent. This is observed as one of the most

important differentiation of biodiesel from diesel, where the peak in the range of 1740–1755/cm is missing (Fig. 3). In the case of diesel, the absence of alcohol or un-reacted methanol has an absorption range of 3600–3500/cm.

IR spectrum of 10% and 15% blended *Glycine max* biodiesel indicated the strong peak of ester at 1234/cm (C–O vibrations). There is not any hindrance observed in the 1750/cm region, but the signals of diesel do meddle with the 1170–1200/cm region. The observed peaks at 2669/cm and 2727/cm as well as in the range of 3100–2700/cm is for the absorption of C–H bond. Table 3 illustrates peak point and AUC (area under the curve) of diesel, *Glycine max* biodiesel and its blends.

UV-Spectroscopy Analysis

Occurrence and absence of aromatics in diesel and biodiesel are differentiated by UV spectroscopy, respectively. Biodiesel has a negligible absorbance in comparison to aromatic compounds at the same frequency when diluted with n-heptane [18]. In the current study, biodiesel was produced from *Glycine maximal* and blended with diesel at 5, 10, 15 and 20%. With n-heptane, these samples of blended biodiesel and diesel were diluted to take the absorbance in the quantifiable range of spectrophotometer. The n-heptane in a quantity of 9.3 ml was mixed with

Table 3 AUC (Area under curve) of diesel, *Glycine max* biodiesel and *Glycine max* blended biodiesel

Diesel		<i>Glycine max</i> biodiesel oil		5% blended biodiesel		10% blended biodiesel		15% blended biodiesel		20% blended biodiesel	
Peak point	Area	Peak point	Area	Peak point	Area	Peak point	Area	Peak point	Area	Peak point	Area
540.07	20.989	597.93	4.674	582.5	6.314	590.22	18.5	586.36	8.4	582.5	9.506
725.23	51.097	721.38	21.138	725.23	21.774	725.23	47.813	725.23	27.941	725.23	26.968
810.1	17.289			810.1	5.702	813.96	10.573	810.1	5.939	810.1	6.896
		910.4	6.501								
964.41	33.571	960.55	7.552	968.27	13.784	968.27	24.131	968.27	13.496	968.27	13.271
1161.15	34.189	1165	19.597	1161.15	15.21	1161.15	40.53	1161.15	21.189	1161.15	18.875
		1234.44	21.204			1234.44	31.638	1234.44	10.147		
1373.32	43.694	1373.32	11.296	1373.32	13.014	1373.32	31.64	1373.32	16.498	1373.32	15.56
1458.18	69.963	1458.18	20.279	1458.18	22.079	1458.18	52.574	1458.18	26.427	1458.18	26.359
1600.92	25.542			1600.92	5.933	1604.77	12.145	1600.92	6.488	1600.92	7.047
1747.51	30.346	1747.51	24.255	1747.51	17.496	1747.51	44.081	1747.51	22.452	1747.51	22.111
1886.38	14.422			1882.52	5.858	1878.67	8.036				
2032.97	10.402	2032.97	6.489	2032.97	6.13	2029.11	9.007	2032.97	6.899	2032.97	8.482
2187.28	13.581			2183.42	5.176	2179.56	6.999	2179.56	4.918	2183.42	7.048
2360.87	9.123	2357.01	2.156	2360.87	3.829	2330.01	16.992				
2407.16	12.827					2403.3	10.657				
2669.48	70.972	2677.2	12.61	2673.34	19.729			2673.34	20.961	2669.48	23.332
2727.35	22.58			2727.35	5.935			2727.35	6.709	2727.35	6.787

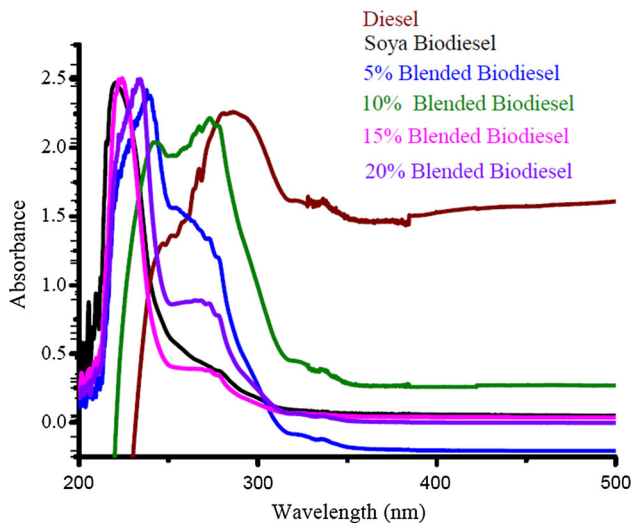


Fig. 4 UV–Vis of diesel, *Glycine max* biodiesel and 5%, 10%, 15% and 20% blended biodiesel

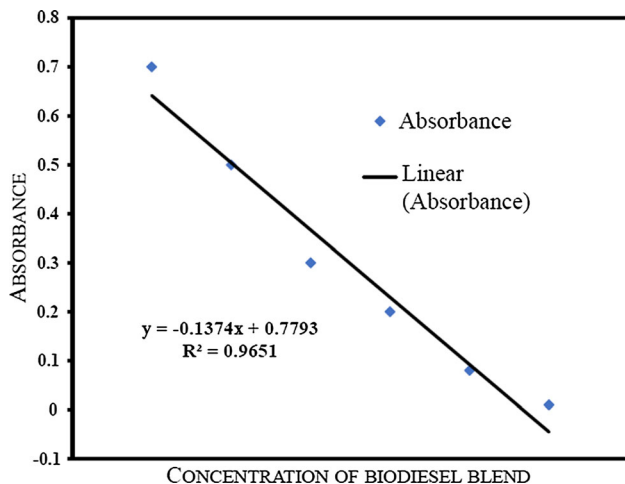


Fig. 5 Absorbance of diesel and blended biodiesel

0.7 ml of the sample, and this process was replicated for 3 times to prepare the final sample. These samples of biodiesel were then measured with the help of UV–VIS spectrometer (Perker Elmer), and an absorbance of these samples was recorded. The absorbance of biodiesel at each wavelength decreases due to dilution with an aromatic compound like diesel (Fig. 4).

With both linoleic acid as well as methyl ester, fully saturated and monounsaturated FFAE in the UV region were not absorbed strongly while polyunsaturated samples absorbed strongly and having characteristic spectra. Diesel absorbs the least followed by 10% and 5% blended biodiesel samples showed the highest absorbance.

The linearity of absorbance declines with the augmentation in biodiesel blending with biodiesel and diesel due to decreased concentration of aromatic compound (Fig. 5). The linear line fitted for absorbance versus the percentage

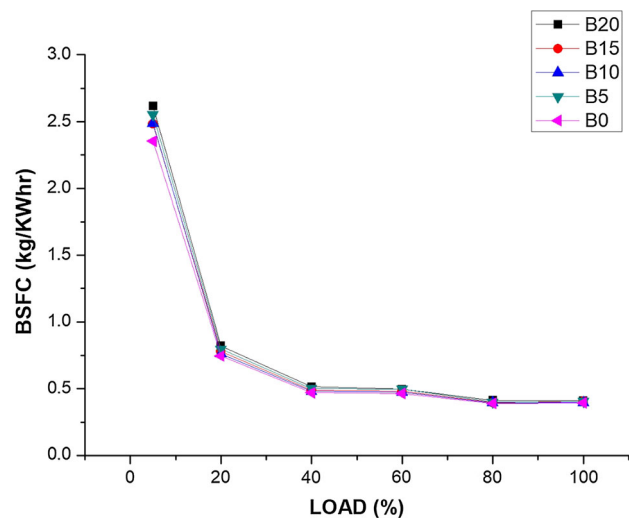


Fig. 6 Variations of brake specific fuel consumption versus load (%) for fuels

of biodiesel at 320 nm showed a high coefficient of determination ($R^2 = 0.9651$).

Brake Specific Fuel Consumption

Figure 6 shows the variation in the proportion of biodiesel blends with the load on the BSFC, at the constant speed (1500 rpm). Generally, biodiesel blends have more specific fuel consumption as compared to that of diesel fuel, apart from having decreasing trend with increasing load. For all tested fuels BSFC is decreased with an increase in load percentage, because percentage in fuel consumption is less as compared to brake power. In the case of biodiesel, the primary reason for higher BSFC was the lower heating value of biodiesel as compared to that of diesel. Biodiesels have poor spray characteristics, and thus have differences in the mixture formation, owing to their higher kinematic viscosity and density, as compared to diesel fuel. Thus, it can be said that more biodiesel is required to produce the same torque. At a lower load, the percentage increase in BSFC was obtained as B5 (7.7%), B10 (5.69%), B15 (5.48%) and B20 (11.13%) compared with diesel. Similarly, at full load, the increase in BSFC was found to be B5 (2.7%), B10 (0.5%), B15 (2.53%) and B20 (3.79%). It can thus be observed that the variation of BSFC with increasing load at different blends of biodiesel is similar to the result obtained by other research work [19, 20].

Brake Thermal Efficiency

Figure 7 describes the alterations in the brake thermal efficiency as a function of load. It indicates that for a given set biodiesel blend, thermal efficiency is less, as compared to the thermal efficiency of diesel. Several factors are

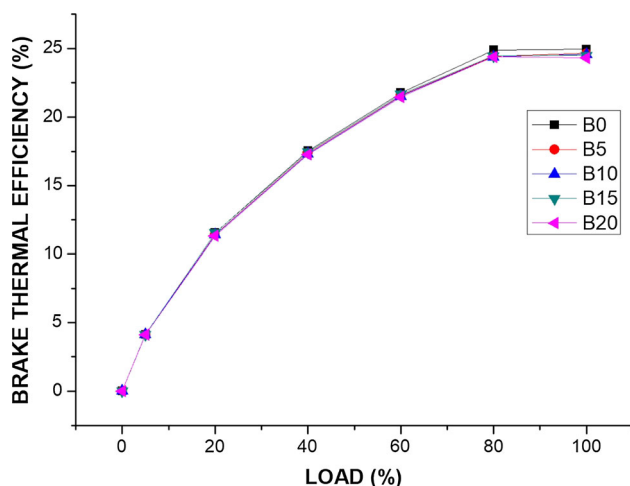


Fig. 7 Variations of brake thermal efficiency versus load (%) for fuels

responsible for the observed lower thermal efficiency of biodiesel blends, such as lower calorific values, poor volatility, slow-burning rate and high viscosity. At a lower load percentage, decrease in BTE was obtained as B5 (0.04%), B10 (0.04%), B15 (0.02%) and B20 (0.16%) compared with diesel. Similarly, at full load, the decrease in BTE was B5 (1.20%), B10 (1.47%), B15 (1.76%) and B20 (2.52%). It has been observed that during the process of blending, the variation in BTE was less in full load condition as compared to the part load condition. This is because of the increase in temperature [21]. It can be observed that the variation of BTE with increasing load at different blends of biodiesel is similar to the result obtained by other research work [22, 23].

Exhaust Gas Temperature

Figure 8 shows the exhaust gas temperature (EGT) variation in comparison with load, for the diesel and biodiesel blends. Exhaust gas temperature is observed to be lower for diesel than that for biodiesel blends. At a lower load percentage, the increase in EGT was obtained as B5 (2.23%), B10 (4.07%), B15 (8.85%) and B20 (12.5%) compared with diesel. Similarly, at full load, the reported increase in EGT was B5 (1.13%), B10 (2.64%), B15 (1.88%) and B20 (3.77%). It augments with the increase in biodiesel proportion in the blend, since, as seen, B20 exhibits higher exhaust temperature than other blends. The larger proportion of biodiesel may lead to the augmentation of the cetane number of the fuel blend. The higher cetane number fuel exhibits lower ignition delay, and consequently, shorter premixed combustion period. It leads to higher exhaust temperature for biodiesel blend. However, biodiesel blends and diesel fuel were observed to have comparable EGT at higher loads. The higher loads require more

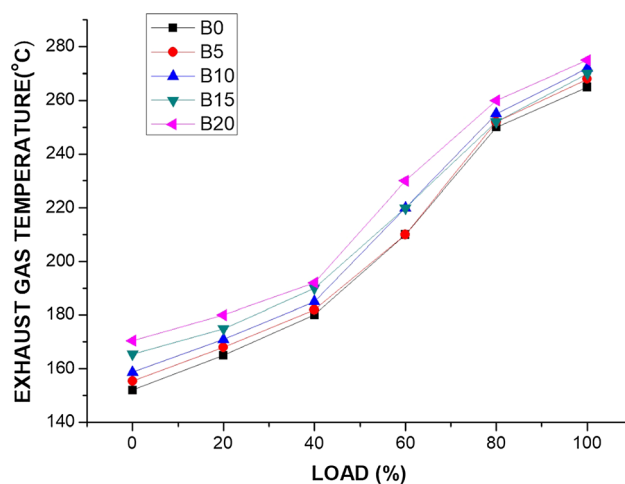


Fig. 8 Variations of exhaust gas temperature versus load (%) for fuels

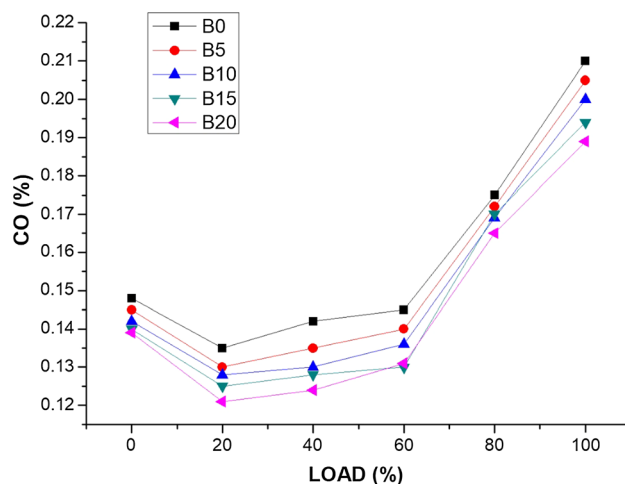


Fig. 9 Variations of CO versus load (%) for fuels

fuel to be injected. Thus, the amount of heat release and hence consequently, the exhaust temperature, is found to be comparable for both, biodiesel as well as diesel. It can be observed that the variation of EGT with increasing load at different blends of biodiesel is similar to the result obtained by other research work [22, 23].

Carbon Monoxide (CO)

Figure 9 shows the carbon monoxide (CO) variation in comparison to load, for the diesel and biodiesel blends. As the rate of the proportion of biodiesel blend increases, the rate of CO emission is decreased. This is because blend in biodiesel produces more appropriate oxidation in comparison to diesel.

It has been observed that the rate of emission of CO decreases initially with load, and later increases rapidly up

to full load. Also, it has been observed that cylinder temperature was low initially in the low load condition, and it increased rapidly as the load was increased. This is because of the enhancement of fuel injection inside the engine cylinder. As the temperature of the engine also increases due to enhancement in the rate of burning of fuel, it results in the decrease in CO. However, CO emission increases rapidly on further loading, as it requires an excessive amount of fuel, which leads to the formation of huge smoke [24, 25]. It was thus obtained that at full load, there was a 2.38%, 4.76%, 7.61% and 10% reduction in CO emission with B5, B10, B15 and B20, respectively [26, 27]. It can be observed that the variation of CO of with increasing load at different blends of biodiesel is similar to the result obtained by other research work [28, 29].

Hydrocarbon (HC)

It was observed that the emission rate of HC decreases with the increase in the proportionate rate of biodiesel (Fig. 10). The emission of HC decreases due to higher cetane number of biodiesel, which results in delayed combustion [19]. It was obtained that at full load of 1.66%, 2.5%, 4.16% and 6.25%, there is a reduction in HC emission with B5, B10, B15 and B20, respectively. It can be observed that the variation in HC with increasing load at different blends of biodiesel is similar to the result obtained by other research work [24–29].

Nitrous Oxide (NO_x)

NO_x emissions are found to be increasing with the increase in proportion of blend (Fig. 11). The main reasons for this are EGT, more oxygen content and faster reaction rate. At a lower temperature, atmospheric nitrogen exists as a stable diatomic molecule, with a small amount of NO_x, but

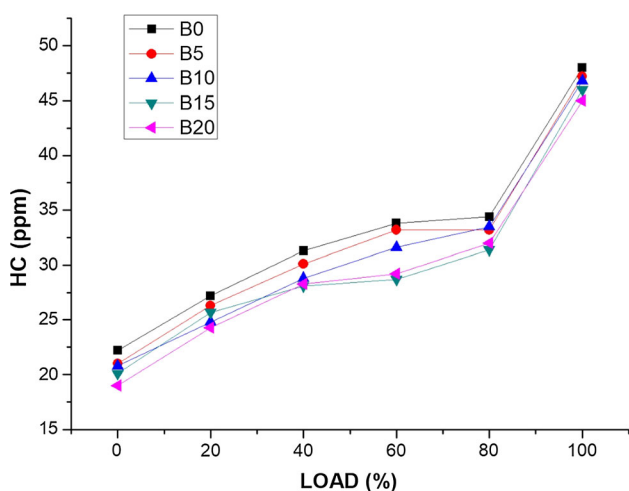


Fig. 10 Variations of HC versus load (%) for fuels

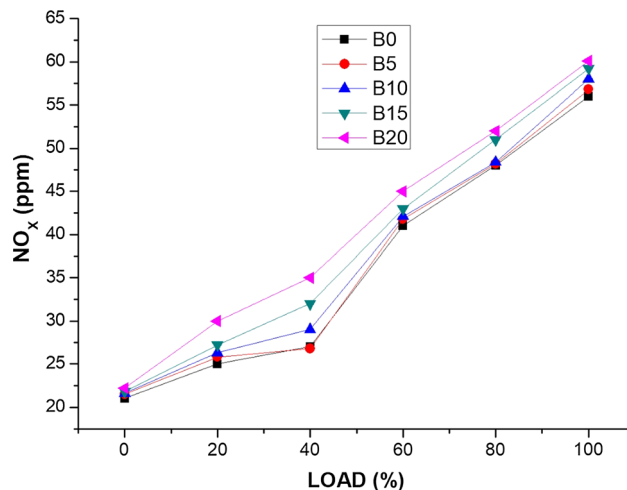


Fig. 11 Variations of NO_x versus load (%) for fuels

at a higher temperature, in the combustion chamber of an engine, some diatomic nitrogen breaks down to monoatomic nitrogen, which is reactive. It was obtained that at full load, there was a 1.42%, 3.57%, 5.71% and 7.32% increase in NO_x emission with B5, B10, B15 and B20, respectively. It can be observed that the variation of NO_x with increasing load at different blends of biodiesel is similar to the result obtained by other research work [19, 20].

Conclusion

The characterization of biodiesel was done by spectroscopic method (FTIR and UV–Vis spectroscopy). The results indicate that biodiesel retains the properties of diesel. The diesel characteristics of *Glycine* biodiesel are almost like those of conventional diesel. *Glycine max* biodiesel infrared spectrum showed the triglyceride ester linkage at 1745/cm. The occurrence of strong ester carbonyl bond (C=O.) indicates the presence of Fatty Acid Methyl Ester (FAME) and is present in all blended biodiesel. The linear line fitted for absorbance versus the percentage of biodiesel at 320 nm showed a high coefficient of determination ($R^2 = 0.9651$).

The performance analysis of the engine has been done using biodiesel at different blending ratios. The BSFC of the engine on blends is higher than of neat diesel operation. The increase in BSFC at full load condition gives the report as B5 (2.7%), B10 (0.5%), B15 (2.53%) and B20 (3.79%). At a lower load percentage, decrease in BTE was obtained as B5 (0.04%), B10 (0.04%), B15 (0.02%) and B20 (0.16%) compared with diesel. Similarly, at full load, the decrease in BTE was B5 (1.20%), B10 (1.47%), B15 (1.76%) and B20 (2.52%). The EGT increased as the function of the concentration of blend. The higher the

percentage of biodiesel in the blend, the higher was the temperature. Similarly, at full load condition increase in EGT was reported as B5 (1.13%), B10 (2.64%), B15 (1.88%) and B20 (3.77%). Increase in the NO_x emission of biodiesel fuelled engine at full load condition was 1.42%, 3.57%, 5.71% and 7.32% with B5, B10, B15 and B20, respectively. The emission of CO and HC reduce appreciably as a result of biodiesel. It was obtained that at full load condition, there was a 2.38%, 4.76%, 7.61% and 10% reduction in CO emission, with B5, B10, B15 and B20, respectively. It was obtained that at full load condition, there was a 1.66%, 2.5%, 4.16% and 6.25% reduction in HC emission with B5, B10, B15 and B20, respectively

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