Chapter 4
Performance Analysis of CI Engine Powered with *Simarouba Glauca* L. Biodiesel Fuel

A. Verma, K. S. Rawat, M. Saify, A. K. Singh, and P. Maheshwari

Abstract In the present work, the performance characteristics of CI engine, powered with *Simarouba Glauca* L. biodiesel blended fuel, have been analyzed at different load conditions. The CI engine test rig has been operated with fuel having different %, viz. 0%, 5%, 10%, 15%, and 20% of *S. Glauca* L. biodiesel. The performance parameters, namely brake thermal efficiency, brake specific fuel consumption, and volumetric efficiency, and emission characteristics such as NO_x, UBHC, and CO_2 have been analyzed. The experimental results revealed that the use of *S. Glauca* L. biodiesel in different % composition significantly affects the engine's performance. An improvement in brake thermal efficiency of the engine was observed when operated with blended fuel as compared to the conventional fuel. The diesel fuel blended with 15% *S. Glauca* L. biodiesel showed better results among all the % compositions studied in the current work.

Keywords Biodiesel · *Simarouba Glauca* L. · Engine performance analysis · Emission control

4.1 Introduction

Due to the global air pollution, the quality of air is continuously decreasing from required standards and the main source of air pollution in cities is motor vehicle, especially diesel [1]. The continuous use of fossil fuel for powering the automobiles exacerbated the environmental condition, and day-to-day depletion of oil reserve causes grave necessity to find alternative fuel. Due to the rising environmental pollution problems and depleting oil reserve, it has become the need of time to make research work more directed toward the development of alternative fuels [2]. Numerous studies have been conducted to explore different renewable fuel to replenish the

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I. Singh et al. (eds.), *Advances in Materials Engineering and Manufacturing Processes*, Lecture Notes on Multidisciplinary Industrial Engineering,
https://doi.org/10.1007/978-981-15-4331-9_4

incessant demand of diesel [3–6]. Biodiesel has shown a positive impact in resolving these issues. Biodiesel as fuel received more attention from last two decades.

India stands first in global pollution death, with 9 million a year, so there is a great need to curb the pollution level. Today, complete transition from diesel to biodiesel engine seems implausible because many problems oriented with biodiesel. The atomization and combustion characteristics of biodiesel are notably different from diesel fuel as high viscosity of biodiesel interferes with injection process and leads to poor atomization [7]. The amalgamation of oil with air contributes to incomplete combustion, leading to heavy smoke emission. Both pour point and cloud point are notably higher than diesel fuel [8]. This high value may cause problem in cold weather. Coming to NO_x emission result showed that in most of cases, NO_x emission increases [9–11]. However, their different blends with diesel can be used result in low CO, PM, and sulfur [12, 13].

India's economy has been experiencing some of the greatest structural changes from 2000 to 2015. India imports approx. 81% of its oil need resulting in high cost of the fuel. Hence, biodiesel seems the most promising alternative of diesel fuel. Biodiesel can be derived from edible and non-edible feedstock [14, 15]. Previous research revealed that production of biodiesel was more focused on edible oil sources [16]. If this trend continues, then incessant production of biodiesel in future may lead to the depravity of edible oil. Production of biodiesel on commence of insecurity of food does not seem a good idea. Biodiesel used in this paper is *Simarouba Glauca* L. which is non-edible seed oil; however, there are many other non-edible seed oils like Jatropha and Mahua, but very few researches have been done on *S. Glauca*. This work explores the use of non-edible feedstock-based biodiesel which is cheap and eco-friendly than conventional diesel fuel. Moreover, the need of importing conventional fuel can be controlled up to some extent as biodiesel can be easily produced in India [17].

Simarouba Glauca L. most commonly known as laxmitaru, samba, or maruba supposed to be originated from America, especially from Amazon rainforest and tropical region of Mexico, Cuba, Haiti, and Central America. Biologically, it is categorized as the family of simaroubaceae quassia. It grows well in the wasteland of Orissa, Karnataka, and Gujarat along with Maharashtra and Tamil Nadu. It is non-edible and has great potential to diminish the import demand [18]. Oil content in *S. Glauca* L. compared to that of Jatropha is of approximate equal amount which makes it more vulnerable to use as biodiesel.

According to the laboratory reports of National Oilseeds and Vegetable Oil Development Board, *S. Glauca* L. in its pure form contains 0.06% of free fatty acid and remains in quality for an average of six months, with melting point of 27 °C. Biodiesel production from *S. Glauca* L. was started from the conversion of seed into oil follow by transesterfication. Transesterification has been proven as most efficient and easiest method as compared to the other production techniques [19]. The crude *S. Glauca* L. oil was transesterified using KOH as catalyst and methanol to form biodiesel. The oil so obtained is green colored, relatively lighter, and less viscous than crude oil found by mechanical expression with odor of sweat. Table 4.1 shows the different properties of *S. Glauca* L. biodiesel and baseline diesel [20].

Table 4.1 Fuel properties of *Simarouba Glauca* L. and baseline diesel [20]

S. No.	Properties	Standard	Range	Simarouba biodiesel	Baseline diesel
1	Kinematic viscosity (Cst) at 40 °C	ASTMD445	1.9–6.0	4.7	1.3–2.4
2	Flash point (°C)	ASTM D93	>130	151	52–96
3	Density (kg/m)	ASTM D4062	870–900	865	832–850
4	Calorific value (MJ/kg)	ASTM D240	–	37.93	45.5
5	Cloud point (°C)	IS:1448	−3 to 12	25	−40
6	Pour point (°C)	IS:1448	−5 to 0	13	−40

4.2 Experiment Methodology

The main objective of the current research work is to analyze the performance parameters of CI engine powered with blended biodiesel fuel at different load conditions. A experimental test rig is developed to undertake the thermal performance evaluation and emission characteristic evaluation, at injection pressure 220 bar, using 5%, 10%, 15%, and 20% biodiesel blends under different load conditions. Figure 4.1 shows the engine test rig (actual and schematic diagram) used in the current research work. The engine specification and operating conditions are presented in Table 4.2.

4.3 Results and Discussion

Figure 4.2 presents the variation of BTE of the engine as a function of load % for different blend % of *S. Glauca* L. oil in the diesel. The BTE of the engine increases with increase in load, and this trend was common for all % of blending. The net heat loss reduces as the engine runs at higher loads, resulting in increase in BTE. At 25% load condition, the highest BTE of 21% was observed for the fuel with 5% blending of *S. Glauca* L. oil in diesel. At 50% load condition, the BTE increases with augment in blend %, reaching maximum 32% at 15% blend condition and then drops slightly to 31% for further increase in blend % of *S. Glauca* L. oil. When load increases to 70%, B15 gets highest BTE of over 37.8%, and B20 has least of 37.3%; however, all these blends have greater BTE than diesel, which means on part load condition biodiesel has better performance than diesel. Now for full load condition, B15 has 40% efficiency compared to diesel BTE of 38%.

Figure 4.3 presents the effect of blend % and load % on the BSFC of the engine. The BSFC of the engine running at diesel fuel was observed to be more as compared to the blended fuel for all load conditions, except at full load. At full load condition, the maximum BSFC was observed for the diesel fuel blended with 5% *S. Glauca* L.

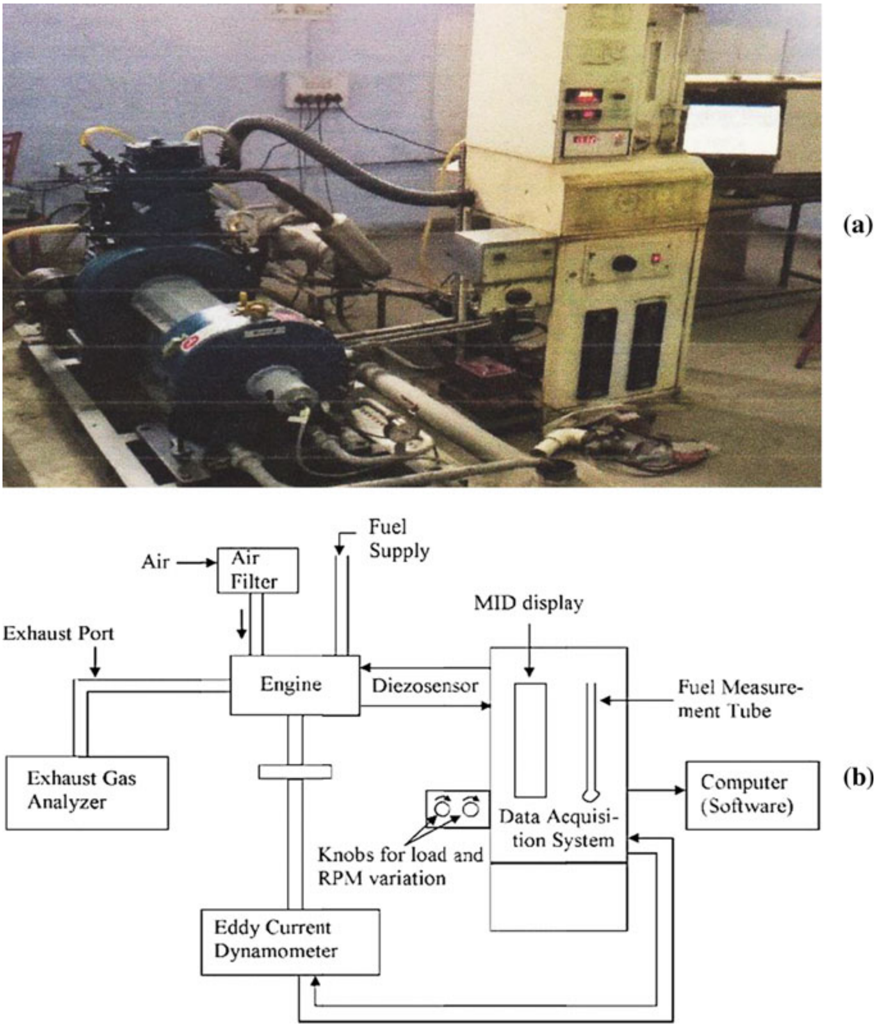


Fig. 4.1 Experimental test rig

oil. It can be clearly seen from the figure that the BSFC decreases with increase in load % of the engine, irrespective of the blend condition of the fuel. At 25% load condition, diesel has highest BSFC and B15 blend has BSFC less than diesel, i.e., 17.62 MJ/kWh, but the highest among all blend strength. Increasing load to 50% shows entirely different readings, as B10 has highest BSFC of 11.91 MJ/kWh which is less as comparative to diesel's 12.48 MJ/kWh. Further, increasing the load to 75% shows comparative values of BSFC for each blend %; however, B15 has least value of 9.5 MJ/kWh, which proves to be most economical.

Table 4.2 Engine specification

Model	Kirloskar oil engines
Engine	Single-cylinder four-stroke naturally aspirated diesel engine
Bore/stroke/compression ratio	87.5 mm/110 mm/VCR
Rated power	3.5 kW at 1500 rpm
Dynamometer	Eddy current, water cooled
Load sensor	Load cell, type strain gauge, range 0–50 kg
Injection pressure	220 bar
Exhaust gas analyzer	Make-Indus Scientific Pvt. Ltd.
Software	ICEnginesoftV8.5 engine performance analysis software

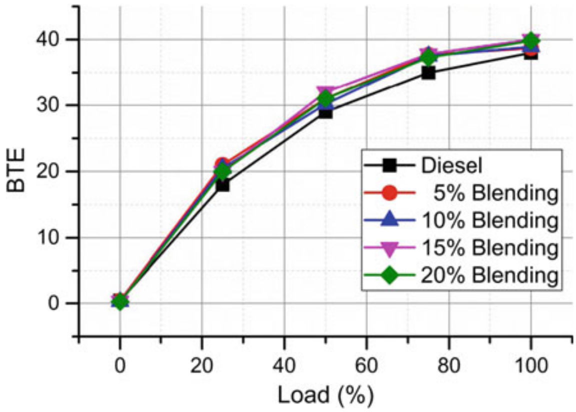


Fig. 4.2 BTE versus load

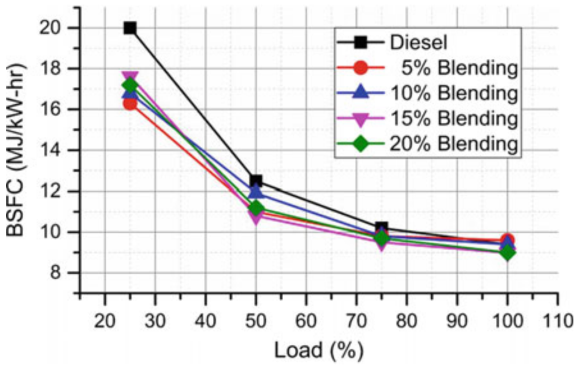
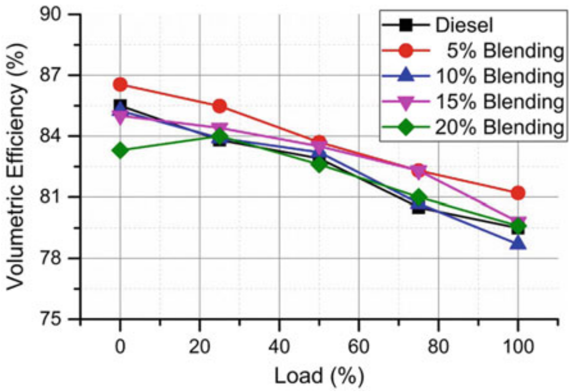


Fig. 4.3 BSFC versus load

The effect of blending % in the diesel fuel on the volumetric efficiency of the engine running at different load conditions is depicted in Fig. 4.4. At no load condition, the volumetric efficiency is almost similar for each blend %, and B05 has recorded maximum of 86.55%, while B20 has minimum volumetric efficiency of 83.3%. When 25% load is applied, slight decrease in volumetric efficiency was observed, where B05 has 85.48% compared to previous 86.55%. Further, for half load condition, B05 showed volumetric efficiency of 83.7% and almost same as B10 and B15, and B20 has least volumetric efficiency of 82.6% almost equal to diesel value, but when load increased to 75% B05 and B15 have almost same volumetric efficiency of 82.3% which was more than diesel value, and B10 and B20 have same volumetric efficiency of 81%, which is also greater than diesel value. On full load condition, slightly noticeable decrement exists for every blend strength except B05, which has maximum volumetric efficiency of 81.2% for B15—it is almost 80% while other blends have less volumetric efficiency. From above discussion, it is clear that there is no considerable effect of load variation on volumetric efficiency and no considerable effect of blend strength too. However, B05 and B15 have throughout better volumetric efficiency at different load conditions.

Along with performance, data emission analysis is also important, of which NO_x emission is one of the key constituents. Figure 4.5 shows variation of NO_x emission as a function of load and blend strength. Minimum NO_x emission was observed at no load condition for all blend strengths. The NO_x emission increases with augment in the % load. At 25% load condition, the diesel fuel has least NO_x emission of 126 ppm and B20 has maximum of 142 ppm NO_x emission among all blend strengths. At each load condition, diesel fuel is having least NO_x emission among their counterparts. It was also observed that the NO_x emission increases as the blend % of *S. Glauca* L. oil is increased, and this trend was common at all load conditions. The highest NO_x emission of 613 ppm was observed for 20% blended fuel when the engine runs at full load, i.e., 100% load condition. NO_x emission cannot be directly related to blend strength. It completely depends upon residual gases present and exhaust gas temperature.

Fig. 4.4 Volumetric efficiency versus load



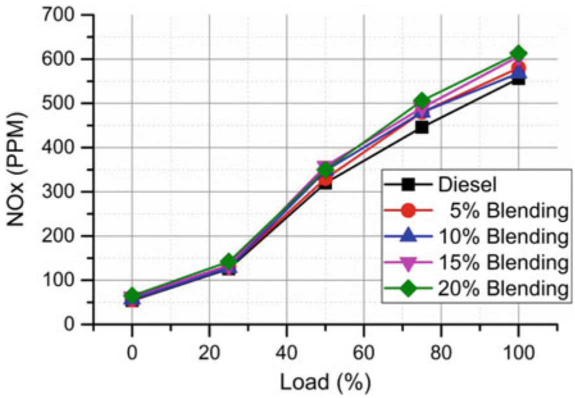


Fig. 4.5 NO_x emission versus load

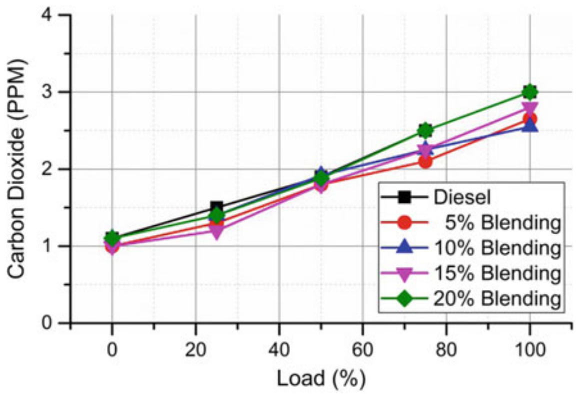


Fig. 4.6 CO_2 emission versus load

Figure 4.6 presents the variation in CO_2 emission with the load and blend strength of the fuel. It is well known that amount of CO_2 in exhaust gases increases with load increments which is actually a direct reconciliation of increased fuel consumption which can be easily compared with Fig. 4.3. Emission of CO_2 can be controlled by amount of fuel injected. At no load condition, each fuel has almost same CO_2 emission of approx. 1 ppm. The CO_2 emission increases with increase in load irrespective of the blend strength of the biodiesel fuel. The CO_2 emission was observed to have slight decrease as the blend strength increases up to 15%, followed by a slight increase for further increase in blend strength, i.e., for 20% blended fuel. B15 fuel was observed to have least emission of 1, 1.2, 1.8, 2.25, and 2.8 ppm at 0, 25%, 50%, 75%, and 100% load conditions, respectively.

UBHC is the indication of direct wastage of energy. Figure 4.7 presents the effects of load and blend strength of fuel on the UBHC in the exhaust of the engine. A general trend of increasing the UBHC was observed as the load increases from 0 to 100%. At no load condition, diesel fuel showed highest UBHC in the exhaust gases. For diesel fuel, the UBHC quantity decreases as the load was increased from 0 to 25%

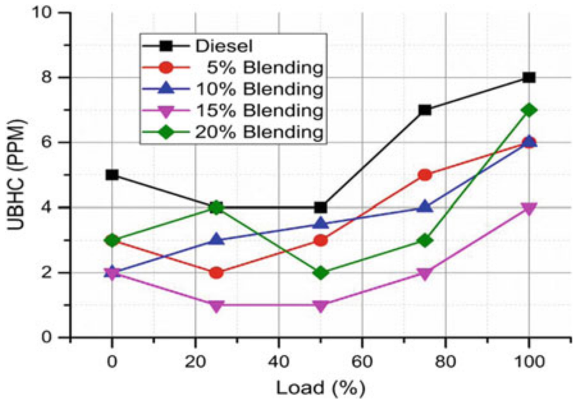


Fig. 4.7 UBHC emission versus load

and then became stable up to 50% of the load followed by an increase in UBHC emission with further increase in load. The fuel with 15% blend of *S. Glauca* L. oil showed better result as compared to the counterparts, where the least quantity of UBHC was observed for all load conditions. The best combination of load and blend strength was observed as 25–50% load with 15% blend strength, respectively, to get minimum UBHC.

The results obtained in the study clearly revealed that the load and blend strength significantly affect the performance and exhaust emission of the CI engine. The *S. Glauca* L. oil is having all the potential to serve as an alternate to conventional diesel fuel. High amount of oxygen present in the biodiesel leads to the improvement in the performance characteristics of the engine. Moreover, the amount of carbon dioxides, UBHC, etc., in the exhaust gas emission can be controlled up to a considerable amount using *S. Glauca* L. oil. The oxygen which presents in *S. Glauca* L. oil helps in complete combustion of fuel, resulting in higher thermal efficiency of the engine. The density of *S. Glauca* L. oil is higher than the diesel fuel, due to which a comparatively lower BSFC is obtained using blended fuel.

4.4 Conclusion

The result obtained through analysis of CI engine fueled with different blends of *S. Glauca* L. at different load conditions showed that these factors have considerable impact on the engine performance and exhaust emission. The CO_2 emission first decreased with increase in blend strength and then increased on an average but never gets higher than that of diesel. BTE for blend strength was always higher than diesel fuel. B5 and B15 had similar and highest BTE among all blend strengths. There was significant decrease in BSFC among biodiesel blend as compared to the diesel fuel. B15 had shown minimum BSFC among all fuels including diesel. Similar result was seen in case of volumetric efficiency. Use of biodiesel reduced the HC emission by

26% at full load, but diesel had recorded least emission at part load. Low BSFC and high BTE are key indication of good engine fuel which is recorded in case of B15 biodiesel blend, consequently having lower emission as compared to diesel were observed for same blend strength. On a single platform, the best overall performance and emission characteristic were observed for B15 blend fuel.

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