

## Research Article

# Performance and Emission Analysis of Common Rail Diesel Engine with Microalgae Biodiesel

Yenda Srinivasa Rao <sup>1</sup> and Tsegaye Getachew Alenka <sup>2</sup>

<sup>1</sup>Department of Mechanical Engineering, Swamy Vivekananda Engineering College, Bobbili, Andhra Pradesh, India

<sup>2</sup>Department of Mechanical Engineering, Wolaita Sodo University, Sodo, Ethiopia

Correspondence should be addressed to Tsegaye Getachew Alenka; [tsegaye.getachew@wsu.edu.et](mailto:tsegaye.getachew@wsu.edu.et)

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Modern common rail diesel engines are normally optimized with commercial diesel. As a result, the engine control unit's calibration is established to achieve the best compromise between performances and exhaust pollutants. Biodiesel has a faster combustion rate and higher combustion chamber temperature than commercial diesel, which necessitates the injection of higher fuel volumes to compensate for the lower calorific value of biodiesel compared to regular diesel. This study showed that by adjusting the mapping of the engine control unit according to the fuel utilised, it is possible to improve the emissions and performance of a common rail diesel engine running on pure *Botryococcus braunii* algae oil biodiesel or a blend of biodiesel and commercial diesel.

## 1. Introduction

While each country bears varying degrees of responsibility for the emission of climate-changing gases into the atmosphere [1]. It is also true that regardless of their culpability, every country today faces the severe problem of climate change's repercussions. This planetary nature of the problem implies that universally approved international policies for gradual reductions in emissions into the atmosphere, as well as common support in anticipation of the large costs required to protect entire populations from the effects of climate change, are required [2]. The necessity to invest in alternative energy such as biofuels derived from crops such as sunflower, soybean, and rapeseed is thus emphasized, especially given the role they may play in achieving the reduction of greenhouse gas emissions. Agriculture's contribution helps us achieve the Kyoto Protocol's goals while lowering pollution levels [3]. A million tonnes of biodiesel produced from domestic crops reduces hydrocarbon and polycyclic aromatic emissions by 80% and particulate matter and fine dust by 50%, respectively. The IPCC identified CO<sub>2</sub> as one of the gases responsible for the greenhouse effect and

human activity as one of the reasons in its first report in 1990. That human activity is behind the acceleration of the heating process and that only by drastically reducing greenhouse gas emissions in the atmosphere will it be possible to avoid exceeding the critical, dangerous thresholds even for the maintenance of life on Earth has evolved [4]. The recent oil crisis, as well as public interest in environmental issues, has prompted further research into all renewable energy options. More and more sustainable energy sources, including biomass, are gaining popularity in the community. The latest official document presented by the EPA is intended to provide information to interested parties who want to evaluate the possibility of using biodiesel as a substitute for commercial automotive diesel [5]. Analysis of data available from the EPA on regulated engine emissions heavy duty can be summarized, which shows the percentage of biodiesel mixed with diesel and the variation of emissions NO<sub>x</sub>, PM, CO, and HC compared to commercial diesel. The reported results are in the most general form possible and summarize a fact known in the literature. As the percentage of biodiesel in a blend with the diesel fuel, HC, CO, and PM emissions decrease while NO<sub>x</sub> increases to

a maximum of 10% for pure biodiesel [6]. The increase in NO<sub>x</sub> emissions with increasing concentration of biodiesel could be a deterrent to the use of biodiesel. The analysis of the averages of the results of the experimental tests available led the EPA to affirm that measurements on blends with 20% of biodiesel show a decrease in NO<sub>x</sub> emissions. Further analysis by the EPA aimed at understanding the phenomenon in which many aspects have been taken into account such as the origin of oil of biodiesel and the type of plant and test condition. The analysis of this pollutant was conducted also according to the type of biodiesel used. This research does not deal with issues such as air quality, production, or distribution costs of biodiesel. It is mainly focused on the environmental impact of biodiesel as a fuel for land traction. All available public data on biodiesel were collected first, and then an in-depth analysis to correlate all the data was performed [7]. The results were presented on the influence of biodiesel on regulated emissions.

## 2. Description of the MultiJet Injection System

The engine on which the testing activity was carried out is the Simpson XRDF model. It is a modern second-hand common rail direct injection diesel generation equipped with a 1910 cm<sup>3</sup> MultiJet injection system of displacement double overhead camshaft distribution and four valves per cylinder. The engine is equipped with a MultiJet injection system. Multiple injections represent a strong technological evolution of the now well-known common rail system [8]. The research center has developed a management system for the combustion process through the use of injections multiple. This MultiJet system allows a strong reduction of emissions of NO<sub>x</sub> and particulates without a significant penalty in terms of costs. The raising of the maximum diesel pressure from 1600–1700 bar, for the improvement of the flue gas post-treatment systems. The first-generation common rail systems have a small injection pilot which is implemented a few milliseconds before the main injection. The concept behind multiple injections is to divide the injection main into a sequence of three close injections such as Pre-Main-After [9]. The preinjection allows controlling the combustion speed of the phase premixed, further reducing the combustion noise compared to the common rail of first-generation. The preinjection behaves in a similar way to the pilot injection while guaranteeing containment of particulate matter (soot) and CO. The engine specification shown in Tables 1 and 2 shows the uncertainty analysis of all the parameters. Figure 1 shows the engine setup with a common rail injection system.

## 3. Characteristics of Algae Biodiesel

Biodiesel is a renewable fuel that may be made from a variety of sources, including a wide range of algae oils [10]. The transesterification method provides for the production of biodiesel appropriate for diesel engines. Biodiesel is typically made from a blend of several transesterified oils, both to account for market availability and to produce a final product that meets the requirements set forth by the numerous directives in place today. Algae oils differ greatly in their properties, partly according to the quantity of fatty

TABLE 1: Engine specification.

Engine	Diesel cycle, 4 strokes, 4 cylinders, bore 92 mm
Stroke	90.4 mm
Total displacement	1910 cm <sup>3</sup>
Relationship of compression	17.5:1
Maximum power	150 hp (110 kW) at 4000 rpm
Maximum torque	305 Nm at 2000 rpm
Distribution	4 valves per cylinder
Diet	Common rail MultiJet direct injection
Alternator	85 A, 14 V
Battery	60 Ah, 12 V

TABLE 2: Uncertainty error analysis.

Parameter	Resolution	Accuracy	Range
CO	1 ppm	±20 ppm (for <400 ppm CO)	0–10000 ppm
Nitrogen dioxide (NO <sub>x</sub> )	1 ppm	±5 ppm (for <100 ppm NO <sub>2</sub> )	0–1000 ppm
Operating temperature –10 to 45°C			
Warm-up time 3 min			
Response time T90 30 sec			
Operating humidity 5–95% noncondensing			

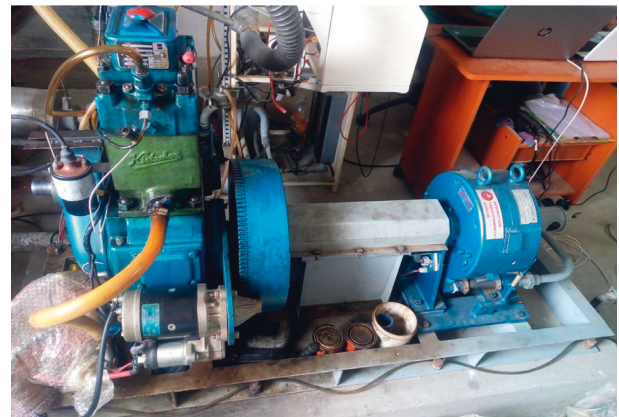


FIGURE 1: Engine setup with common rail injection system.

acids they contain. It is noted that a considerable content of unsaturated fatty acids improves combustion at low temperatures and that the number of cetanes is strictly dependent on the distribution of fatty acids. Algae oils have various proportions of unsaturated fatty acids, which are blended during biodiesel manufacturing [11]. Table 3 shows the characteristics of biodiesel in this research work. Figure 2 shows a photo view of *Botryococcus braunii* algae.

## 4. Calibration Optimizations

The engine was run on 100% pure biodiesel (B100) and a mixture of 50% biodiesel and 50% commercial diesel during the tests (B50) and this same volume procedure was followed by B20. The results were compared to experiments using commercial diesel oil and comparing emissions and performance

TABLE 3: Characteristics of biodiesel.

Properties	Diesel	AME	B50	B20
Cetane number	48	52	51	51
C/H/O (molar ratio)	16:30:0	19:34:2	20:33:1	21:33:2
Density, g/cm <sup>3</sup> (15 C)	0.83	0.89	0.90	0.91
Kinematic viscosity, cSt (37.8 C)	3.3	4.5	4.8	4.9
Net calorific value kJ/kg	43000	36000	42000	44000
Clod point (C)	>4	>4	>4	>4
Carbon content (wt %)	86.5	77.4	74.2	72.1
Hydrogen content H (wt %)	13.4	12	12.2	12.3
Oxygen content O (wt %)	—	10.5	11.1	11.2
Sulfur content S (wt %)	0.05	<0.01	<0.01	<0.01
Stoichiometric ratio A/F	14.5	12.6	12.4	12.5
Iodine number, g I <sub>2</sub> /100g	—	118	119	119
Distillation curve				
10% EV	181	332	352	354
50% EV	255	340	345	347
90% EV	337	350	354	355
F.B.P.	372	353	359	360
Carbon residue (wt %)	0.01	0.05	0.06	0.06
Biodegradability	No	Yes	Yes	Yes

FIGURE 2: A photo view of *Botryococcus braunii* algae.

[12]. The research's objective was to optimize engine control parameters based on the fuel used, to achieve the optimal balance between engine performance and emissions levels once the fuel was known. For this, software was utilised that allows the engine settings regulated by the control unit motor to be changed in real-time and during engine operation. The performance and emissions of the engine fueled with biodiesel and the biodiesel-diesel blend were measured, and mapping was sought that would allow the engine fueled with biodiesel and the biodiesel-diesel blend to run like when it was driven by diesel.

## 5. Result and Discussion

**5.1. Performance.** The performance depicts the maximum performance of the biodiesel-powered engine. It is focused on finding engine characteristics that permitted a biodiesel-fueled engine to generate the same torque and maximum power as a diesel engine. Polluting pollutants from engine exhaust were not taken into consideration during this period

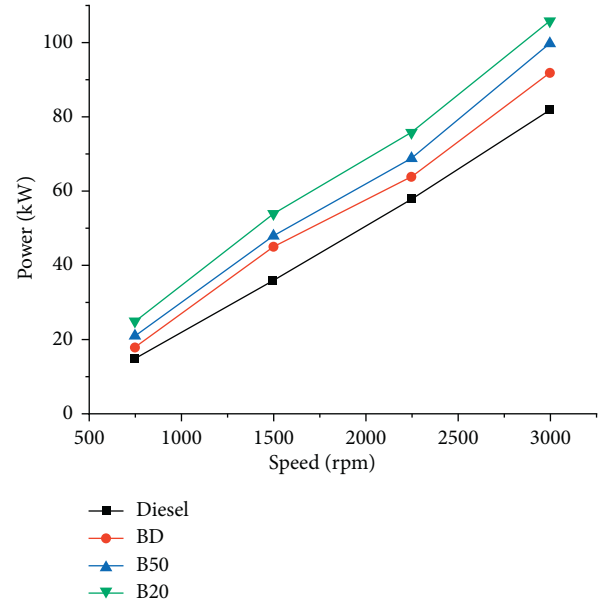


FIGURE 3: Power vs speed.

[13]. Figures 3 and 4 show the torque and the maximum power relative to three different blends. The torque required by the control system, which governs the amount of fuel injected per cycle, injection timing, and boosts pressure, was the control unit parameter on which the major action was performed. Due to the various characteristics of the fuel used, the performance of the engine when fueled by diesel is significantly lower [14]. The mass of fuel injected and the injection advance fails to account for biodiesel's increased calorific value and heat release rate, which differs from diesel fuel. To achieve the same performance as a diesel engine, it was essential to increase the mass of fuel injected per cycle.

**5.2. Pollutant Emissions.** In particular, the improvements that can be obtained for CO and NO<sub>x</sub> emissions will be analyzed by modifying some engine parameters. In this

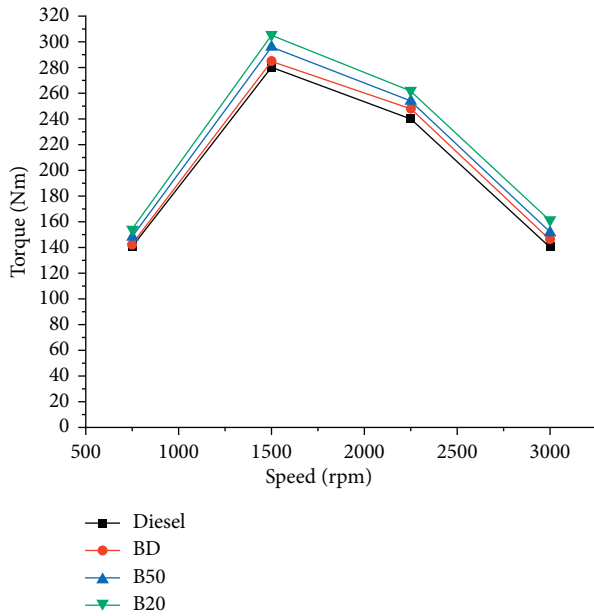


FIGURE 4: Torque vs speed.

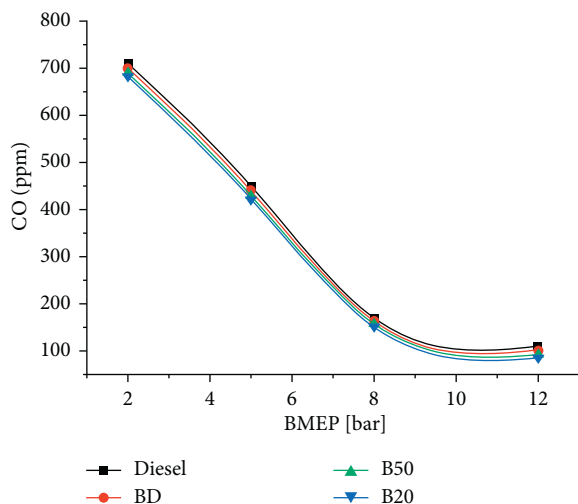


FIGURE 5: CO emission with bmep @ 1500 rpm.

research, the trends of carbon monoxide emissions will be shown (CO) and nitrogen oxides (NOx) for two different fuels [15]. The results will be compared with the emissions measured by fueling the engine with commercial diesel fuel. Furthermore, it is specified that the emissions of nitrogen oxides for all the fuels analyzed were not corrected with the air humidity in aspiration. However, the results shown are congruent with each other. In this experimental activity, no particulate matter (PM) measurements were made due to its low concentration which does not allow a reliable measurement with a smoke meter conventional [16].

Figures 5–10 show the trend of the exhaust emissions in the case in which the engine was fueled with a blend of 20% and 50% biodiesel with diesel commercial for automotive

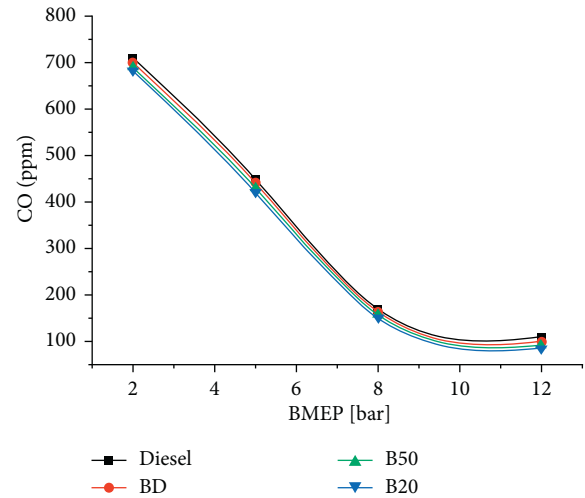


FIGURE 6: CO emission with bmep @ 2000 rpm.

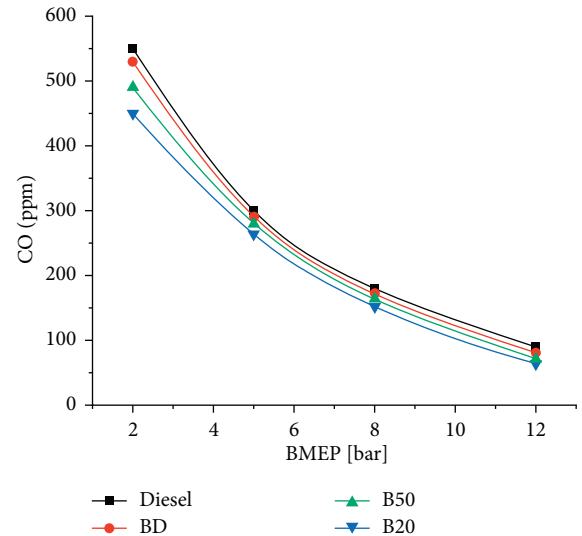


FIGURE 7: CO emission with bmep @ 3000 rpm.

(percentages by volume). The experimental results highlight a fairly similar behavior for the B20 mixture and diesel fuel [17]. However, there is from observing that even at 20% (B20) the NOx emissions are slightly higher and those CO lower, compared to a diesel with the standard calibration of the engine control unit as already observed for the case of pure biodiesel [18]. NOx emissions increase while those of CO decrease. The explanation of these results is to be found in the different chemical/physical characteristics of the fuels, in particular, in the different curves of distillation and the presence of an oxygen molecule in the chemical structure of the biodiesel [19]. These properties result in faster burning and local peaks of higher temperatures than diesel. To take advantage of lower CO emissions and better combustion of biodiesel, the standard calibration of the engine ECU has been modified to improve the level of NOx emissions [20].

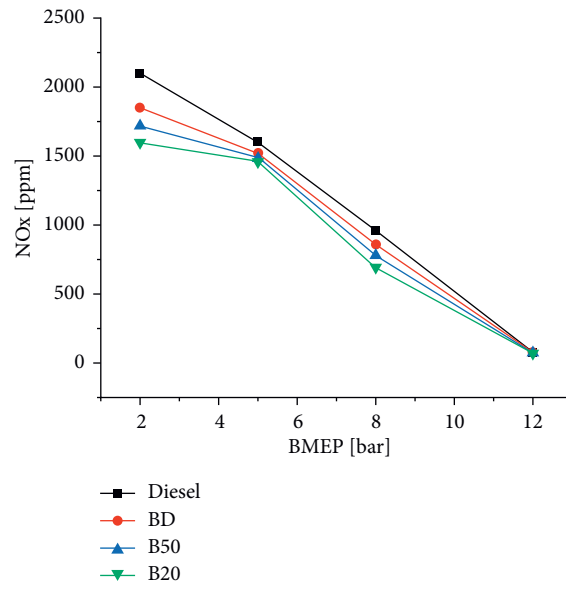


FIGURE 8: NOx emission with bmep @ 1500 rpm.

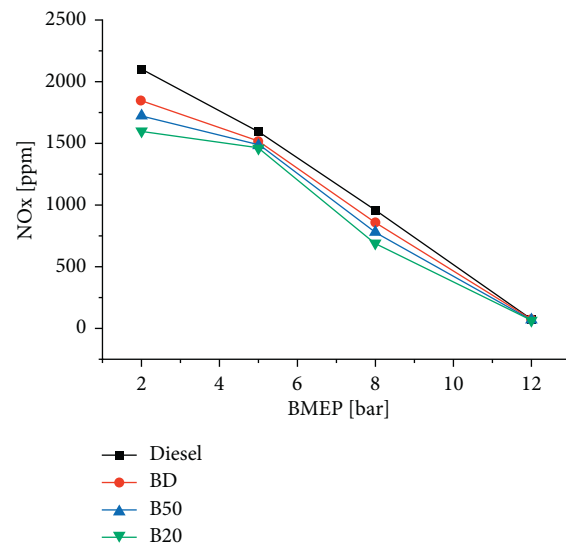


FIGURE 9: NOx emission with bmep @ 2000 rpm.

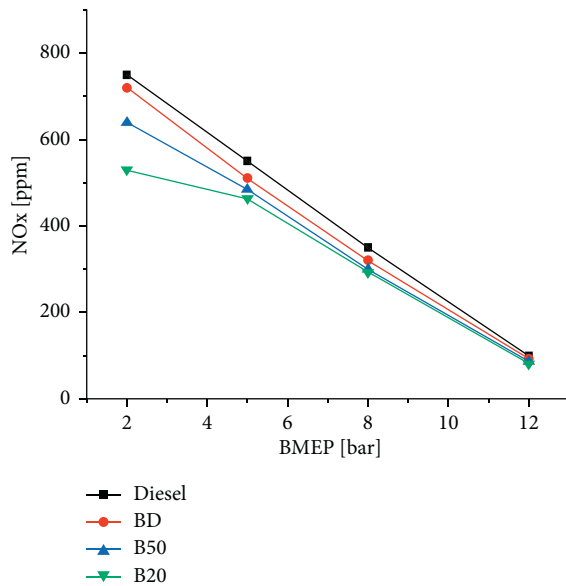


FIGURE 10: NOx emission with bmeep @ 3000 rpm.

## 6. Conclusion

In recent years, biodiesel has aroused a lot of interest thanks to its biodegradability and the absence of sulfur, and its low environmental impact in terms of global warming due to carbon dioxide emissions. In this research work, we analyzed the state of the art of biodiesel and its applicability as a fuel in modern fast diesel engines. It has analyzed the performance and emissions of the latest common rail diesel engine generation fueled with pure biodiesel and with a blend of biodiesel and diesel then compared them with diesel to verify their applicability. The activity was then conducted on the optimization of the engine parameters managed by the engine control unit to improve the behavior of the engine which varies with the fuel used. Typically, a modern diesel engine is powered by biodiesel without any modification to the engine calibration. The emissions of nitrogen oxides increase as the concentration of carbon monoxide in the exhaust gas decreases. These results are due to the chemical characteristics of the biodiesel (presence of an oxygen molecule in the chemical structure) that make combustion faster but with very high local temperature peaks.

## Abbreviations

CO: Carbon monoxide  
 EPA: Economics of biofuels  
 HC: Hydrocarbon  
 IPCC: International Panel on Climate Change  
 NOx: Nitrogen oxides  
 PM: Particulate matter.

## Data Availability

The data used to support the findings of this study are included in the article.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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