



Assessment of using Soybean Biodiesel Fuel on Performance and Exhaust Emission Characteristics of a Common-rail Diesel Engine (OM355)

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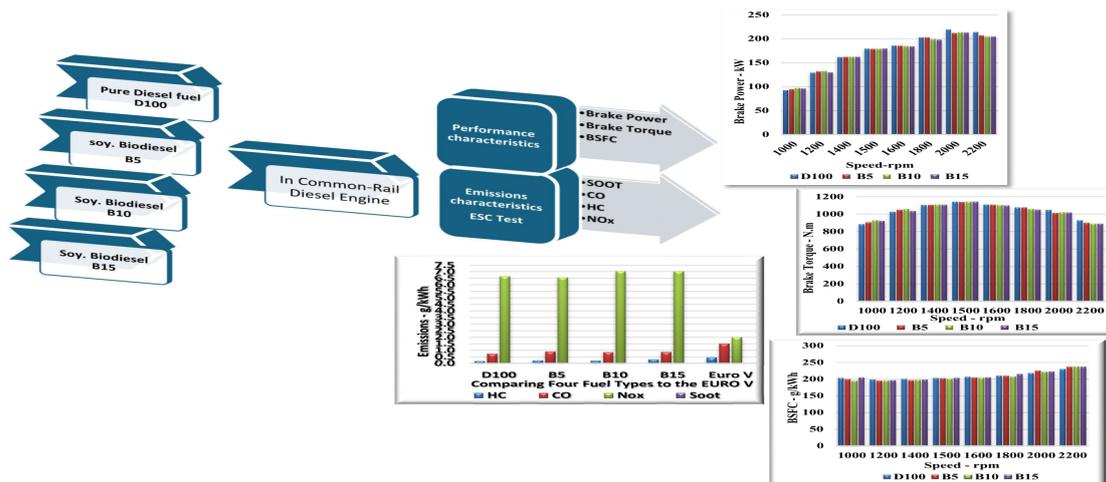
Emission Characteristics

ABSTRACT

The impact of performance and exhaust emission features of a common-rail diesel engine OM355 using a biodiesel/diesel mix (volume ratios of B5, B10, and B15) was analyzed in this study. Between engine speeds of 1000 and 1500 RPM, there was an observed increase in power and torque, with enhancements of 5% and 0.5%, respectively. Conversely, at elevated engine speeds, specifically from 1800 to 2200 RPM, both power and torque exhibited a reduction ranging from 1 to 4% in comparison to conventional diesel fuel. The brake-specific fuel consumption (BSFC) decreased by 4 to 1% at low and medium speeds, particularly between 1000 and 1500 RPM, due to the reduction in energy content from using soybean biodiesel. However, at high speeds in the range of 1800 to 2200 RPM, BSFC increased by 1 to 3.5%. In addition, the results of the emissions test indicated that emissions from mixed fuels were significantly higher than those from regular fuel or diesel owing to the lack of any engine modifications. Based on the test results, despite the increase in pollutant emissions using mixed fuels, the emission levels of the aforementioned fuels were within the Euro 5 standard limits. Considering that diesel engines operate optimally at middle speeds, which is their maximum torque range, and considering the engine performance features, the utilization of biodiesel blends B5, B10, and B15 is acceptable for the engine performance. To reduce the adverse effects of biodiesel combustion, various methods, such as preheating the fuel, increasing the fuel rail pressure, decreasing the injection duration, using additives, and retuning electronic engine control (ECU) units based on the biodiesel characteristics, could be utilized as a viable replacement in diesel engines.

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Graphical Abstract



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NOMENCLATURE			
BSFC	Brake Specific Fuel Consumption	B5	Biodiesel 5%
BTE	Brake Thermal Efficiency	B10	Biodiesel 10%
CR	Common-Rail	B15	Biodiesel 15%
CI	Compression-Ignition	D100	Neat Diesel
PN	Particle Number	ESC	The steady-state European Stationary Cycle
PM	Particle Matter	(ΔX)	Uncertainty of a measured variable
LCV	Lower Calorific Value	σ	Standard deviation
SFC	Specific Fuel Consumption	ξ	Denotes an individual experimental reading
CO	Carbon monoxide	R	Function of the measured variables
UHC	Unburned Hydrocarbon	ΔR	Uncertainties of the calculated
NO _x	Nitrogen Oxide	RMS	Root Mean Square
ECU	Electronic Control Engine	n	the total number of readings
TDC	Top Dead Center	λ	Air-Fuel equivalence Ratio
EGR	Exhaust Gas Recirculation (EGR)	PPM	Parts Per Million
RCCI	Reactivity Controlled Compression Ignition (RCCI)		

1. INTRODUCTION

Scientists continue to produce energy from renewable resources because of the depletion of fossil fuels and the increase in their prices. Biodiesel may be a potential replacement for diesel fuel because of its simple manufacturing method, compatibility with standard diesel engines, and low pollution. Biodiesel did not require any modifications. Utilizing animal fats and waste cooking oils as feedstock offers a cost-effective solution to the economic challenges associated with the raw material supply. Combustion of biodiesel derived from these sources has been shown to significantly decrease emissions of unburned hydrocarbons and carbon monoxide, while only causing a marginal increase in nitrogen oxide (NO_x) emissions. Biodiesel fuel contains no sulfur; therefore, biodiesel is different from diesel (1). The cetane number, flash point, viscosity, and oxygen content in biodiesel are all greater than those of regular diesel fuel. All of these properties affected on the emissions of pollutants.

A study on particulate matter emissions from common-rail diesel engines indicated that biodiesel/diesel blends exhibited a similar geometric mean particle diameter but a lower particle number concentration compared with diesel fuel. Observations indicated that increasing engine speed and load led to a reduction in particle concentration, while the particle size exhibited no significant variation. The study also reported a reduction in both the total particle count and particle mass per unit volume when biodiesel was blended with diesel (2). An experimental investigation was conducted on a common-rail diesel engine fueled with biodiesel–bioethanol blends. Among the tested formulations, B20 and B20E5 demonstrated superior brake-specific fuel consumption (BSFC) and improved brake thermal efficiency (BTE) compared to conventional diesel. These blends also produced notable reductions in carbon monoxide (CO) emissions and

particle number concentrations. Additionally, the incorporation of ethanol contributed to lower nitrogen oxide (NO_x) emissions, a phenomenon attributed to ethanol's cooling effect, which reduces peak combustion temperatures during homogeneous exothermic reactions and thereby suppresses overall NO_x formation (3). The behavior of a diesel engine equipped with a high-pressure common-rail (CR) injection system was investigated to evaluate the performance characteristics of biodiesel under advanced operating conditions, the results showed that higher viscosity delayed fuel injection and impaired atomization. The smaller droplet size of biodiesel contributed to lower CO₂ emissions compared with fossil fuels. In addition, biodiesel contained more oxygen than diesel; as a result, nitrogen oxide (NO_x) emissions increased, whereas suspended particulate matter decreased (4). An investigation was carried out to analyze submicron particle emissions from compression ignition (CI) engines. The findings demonstrated that biodiesel reduced the particle number (PN) and particulate matter (PM) emissions. Moreover, the findings refuted the widespread belief that oxygen-rich fuels inevitably increase the nitrogen oxide (NO_x) emissions. The oxygen present in the ester molecules lowered the NO_x emissions and acted as an anti-knock agent. Increasing the load level caused the NO_x emissions to decrease, whereas the other PM emissions increased. Furthermore, biodiesel content above 10% reduced soot particle formation and did not significantly affect the adsorbed mass of hydrocarbons (HC), thereby enhancing organic solubility under all operating conditions (5). According to an experimental study, the fuel-generated power was equal for both biodiesel and diesel under partial load operation. Under full-load operation, engine power experienced a slight decline attributable to the lower calorific value of biodiesel, although the magnitude of this reduction was minimal. Biodiesel's intrinsic oxygen content played a key role in lowering emissions of particulate matter, carbon

monoxide (CO), and unburned hydrocarbons. These results indicate that biodiesel represents a promising cleaner fuel alternative for diesel engine use (6). Several factors influence the emissions and performance of biodiesel. The proven factors were the biodiesel mixing ratio, biodiesel properties, engine type, operating circumstances, and addition of any type of additive. Because of the mixed fuel had a lower LCV and a higher BSFC than diesel, power reduction was observed in the blended fuel. A few problems associated with the use of an inline injection pump to inject fuel are that fuel injection is based on engine speed, the maximum fuel pressure is low, and multiple injections cannot be used in this case. The monophasic injection method restricts the mixing of two or more substances. As a result, zones of low and high richness were identified in the study area (7). In one study, bioethanol–gasoline mixtures were tested in a spark-ignition (SI) engine to reduce fossil fuel consumption. The thermal efficiency ($\eta_{th,b}$) decreased as the ethanol percentage increased, whereas the latent heat of evaporation increased with higher ethanol content. At a fixed equivalence ratio, raising the ethanol content led to a decrease in both air mass intake and volumetric efficiency. Consequently, the reduced volumetric efficiency combined with the higher latent heat of ethanol caused a drop in the air–fuel mixture temperature, resulting in increased instances of misfires and flame extinction (8). An experimental study reported that marine engines can use biodiesel from renewable sources as a substitute for petroleum diesel because it meets diesel fuel quality standards. Because marine engines operate on various fuels, biodiesel represents a valuable alternative for reducing harmful emissions (9). Research has shown that engines running on soybean biodiesel experience a decrease in torque and an increase in brake-specific fuel consumption (BSFC) relative to conventional diesel, primarily due to biodiesel's lower energy content. At the same time, the use of biodiesel significantly reduced emissions of unburned hydrocarbons and carbon monoxide (CO) by 28 to 46%. In contrast, nitrogen oxide (NOx) emissions increased, and CO₂ concentrations rose by 1.46 to 5.03%. Moreover, blending biodiesel with diesel was observed to shorten the ignition delay and reduce the intensity of the peak during homogeneous combustion (10). Experiments with water–biodiesel emulsions in a compression ignition (CI) engine demonstrated that soybean biodiesel blends significantly reduced smoke, carbon monoxide (CO), and hydrocarbon (HC) emissions compared to conventional diesel. Nevertheless, these blends did not achieve additional reductions in nitrogen oxide (NOx) emissions. The emulsified fuel exhibited a lower specific fuel consumption (SFC) at water concentrations of up to 10%, and the maximum CO and HC emissions also decreased. These reductions were significant but diminished at water concentrations of $\geq 10\%$ (11). A study was carried

out to assess how injection timing and pressure influence emissions in a compression ignition (CI) engine fueled with soybean biodiesel, with particular emphasis on soot and smoke production. Although using biodiesel in common-rail CI engines is commonly associated with higher nitrogen oxide (NOx) emissions, it may simultaneously contribute to increased smoke formation. However, simultaneous reductions in CO and HC under certain operating conditions have been reported. Experiments were performed at post-injection timings of 15°, 30°, and 45° after top dead center (TDC) and at injection pressures of 550 and 650 bar. The findings revealed that, in general, soybean biodiesel reduced CO, HC, and NOx emissions; however, specific combinations of injection timing and pressure led to increased smoke and NOx levels (12). The study investigated the effects of injection pressure on ignition behavior and pollutant emissions in a common-rail (CR) internal combustion engine fueled with palm oil biodiesel. The fuel's elevated cetane number and inherent oxygen content were found to improve ignition performance. At low engine speeds, biodiesel atomization was more difficult. However, the researchers demonstrated that atomization could be improved by increasing the injection pressure, even without engine modifications. The findings further showed that nitrogen oxide (NOx) emissions rose with increasing injection pressure. In addition, the application of exhaust gas recirculation (EGR) has been reported to mitigate pollutant formation (13). Additionally, the effects of blending graphene nanoparticles with soybean oil–based biodiesel on the performance and emission characteristics of compression ignition (CI) engines were investigated. When tested under a 12 kg load, the B60GNP100 blend outperformed conventional diesel, recording the minimum brake-specific fuel consumption of 12.58% and attaining the maximum brake thermal efficiency of 27.13% (14). Biodiesel blends were analyzed to determine their impact on the efficiency and pollutant features of common-rail CI engines. The study included both simulated and experimental tests under three loading conditions. An increase in the proportion of biodiesel within the fuel blend was found to reduce engine power output, while simultaneously leading to higher brake-specific fuel consumption (BSFC) and elevated nitrogen oxide emissions. The findings revealed that fuel blends with a higher share of biodiesel relative to gasoline produced comparatively lower emissions of smoke, unburned hydrocarbons (HC), and carbon monoxide (CO). This study suggests that biodiesel has the potential to improve the performance of compression ignition (CI) engines (15). For instance, one investigation employed a reactivity-controlled compression ignition (RCCI) approach, where a gasoline–diesel/biodiesel blend incorporating waste cooking oil was used to take advantage of the complementary characteristics of the different fuel components. The experiments showed that

unsaturated fatty acids burned faster than saturated fatty acids. The use of unsaturated lipids shortened the engine start time, whereas saturated fatty acids had no significant effect on fuel consumption (16). An experimental investigation was carried out to assess how castor oil-derived biodiesel influences both the emission characteristics and performance behavior of diesel engines. The B15 blend was the most effective in reducing particulate matter at 50% load, although the brake-specific fuel consumption (BSFC) increased for the B20 and B30 blends, along with higher nitrogen oxide (NO_x) emissions. Under quarter-load operating conditions, noticeable decreases in nitrogen oxide (NO_x) and particulate matter (PM) emissions have been reported (17). A study conducted three-dimensional modeling of split-injection schemes to evaluate their effects on pollutant formation and the performance characteristics of indirect injection (IDI) combustion engines. The main challenge in reducing diesel engine pollutants was identified as the inverse correlation between smoke and nitrogen oxide (NO_x) emissions. The application of split injection has proven to be an efficient strategy for concurrently lowering soot and nitrogen oxide (NO_x) emissions in diesel engines (18). A study examined the impact of adding diethyl ether (DEE) to diesel-biodiesel blends on engine performance and exhaust emission behavior. The study revealed that the addition of 5% DEE to diesel fuel resulted in a 5.9% decrease in fuel usage and a 9.6% boost in thermal efficiency, while lowering NO_x emissions by 20.5% (19, 20). A study conducted consumption and emission tests on a single-cylinder, four-stroke diesel engine at various operating loads with biodiesel produced from the distillation of soybean and coconut oil. The addition of distilled biodiesel from soybean and coconut oil to all blends resulted in a maximum improvement in brake thermal efficiency of 56.08% and a reduction in specific fuel consumption of 18.33% compared to diesel fuel. Adding distilled biodiesel to diesel fuel resulted in a maximum reduction of 30% in carbon monoxide emissions in all blends (21).

An investigation was carried out to assess how the addition of titanium dioxide nanoparticles to biodiesel influences combustion dynamics and emission characteristics in a compression ignition engine. According to the study, titanium dioxide nanoparticles decreased CO emissions by 30% and HC emissions by 21.5% when the engine operated at higher speeds and concentrations. When the fuel burns more completely due to the titanium dioxide nanoparticles, there was a 15% increase of CO₂ emissions. The more the speed of the engine increased, the more NO_x emissions decreased by 20% when TiO₂ nanoparticles were added (22).

The mass-based fuel injection system in CR diesel engines requires precise air-fuel ratio control to reduce emissions. The onboard electronic control unit estimates

the amount of fuel mass to be injected for combustion using the sensor data of the rail pressure, fuel temperature, engine speed, intake air mass and gas pedal position. In this system, the injector supplies fuel at high pressure only when the engine requires it to operate. Unlike other systems, CR technology separates the production pressure from the injection. In a CR diesel engine, the pump continues to supply fuel to the rail and behind the injectors depending on the engine control mode. Multi-stage injection can be performed during working cycles, unlike the linear injection fuel delivery system in the CR system. This implies that the primary injection stage is responsible for smooth engine operation, the main injection stage is responsible for producing the desired power, and the secondary injection stage is responsible for minimizing emissions.

Based on the above discussion, soybean biodiesel fuel reduced pollutants such as carbon monoxide and unburned hydrocarbons, except for nitrogen oxides, compared with conventional diesel fuel, without requiring fundamental changes to the engine under test. However, it adversely affects the performance characteristics of the engine under test, such as power, torque, and brake-specific fuel consumption.

Some studies on biodiesel did not inform the emission standards of the test engine, while others focused on engines with standards below Euro 5 standards. In contrast, studies examining the effects of biodiesel in engines compliant with Euro 5+ and Euro 6 emission regulations remain scarce. This gap is particularly significant, given the tightening of global emission frameworks that demand cleaner combustion strategies.

To fill this research gap, the current study assessed the performance and emission behavior of an OM355 diesel engine, produced by IDEM Co., after its fuel system was upgraded from an inline injection pump to a high-pressure common rail configuration. With the addition of after-treatment technologies, the engine's emission compliance improved from Euro 4 to Euro 5 Evv, a level situated between Euro 5 and Euro 6 standards. This study examined the effects of soybean biodiesel under Euro 5+ conditions, utilizing the steady-state European Stationary Cycle (ESC) protocol as a method for engine certification, without making any modifications to the engine.

In this study, an electronically controlled high-pressure common-rail diesel engine fueled with soybean biodiesel/diesel blends was tested on an engine bench to analyze the effects of different blend ratios on the combustion characteristics. The test fuels consisted of diesel and biodiesel blends, with pure diesel denoted as D100. The blends were prepared at volumetric ratios to produce three fuels with different B5, B10, and B15.

The study employed the European Stationary Cycle (ESC) testing method, in accordance with engine certification, to measure exhaust emissions from the

diesel engine. The evaluated performance and emission characteristics included power and torque output, brake-specific fuel consumption, and emission pollutants contained CO, HC, NO_x, and soot with no adjustments made to the engine during the experiments.

2. MATERIAL AND METHODS

This study describes an experiment on a CR diesel engine utilizing 5%, 10%, and 15% volumetric biodiesel mixtures. The volumetric percentages of the mixtures were denoted as B5%, B10%, and B15%. The pollutants and performance characteristics of the diesel engines were measured at partial and complete loads using the selected fuel mixtures. The tests were performed at the engine laboratory of IDEM Company.

2. 1. Materials

2. 1. 1. The Engine Specifications A modern CR diesel engine (OM355) was used in this study, and its technical data are presented in Table 1.

2. 1. 2. Test Equipment The exhaust gases and performance features of the CR diesel engine were tested and evaluated at the Iranian Diesel Engine Manufacturing Co. (IDEM) engine test cell. The test equipment used, as shown in Figure 1, is described as follows:

- **Hydraulic Dynamometer:** A hydraulic brake was employed on the engine to monitor and quantify its key performance parameters.

- **Various Sensors:** Engine power, brake torque, and other variables are measured using the sensors available in the test cell. In addition, the main variables (temperature, pressure, etc.) essential for engine performance were measured.

- **Fuel Consumption Meter:** The BSFC was measured using the AVL 733S digital flowmeter with up to one-thousandth accuracy in kilograms per hour.

- **Exhaust Emissions Measurement Device:** Emissions from the engine were measured using AVL DiCom 4000, which was manufactured in Austria. The pollutants that were measured were NO_x, HC, λ, CO₂, CO, and opacity (soot).

- **Computerized data acquisition system:** Data were acquired using a computerized data acquisition system.

2. 1. 3. Fuel Regular diesel fuel used in Iran was utilized as the base fuel, as well as soy. Biodiesel was used as the fuel in this investigation. This research analyzed the performance characteristics of the base fuel as well as soy-derived biodiesel, with their respective properties summarized in Tables 2 and 3. B5, B10, and B15 denote blended fuels with 5, 10, and 15% biodiesel in pure diesel fuel, respectively. D100 denoted base fuel.

TABLE 1. Engine OM355 Characteristics- courtesy of IDEM Co. brochure

Model	OM355
Engine type	A vertical, turbocharged diesel engine equipped with a CR fuel system
Number of Cylinders	6 in Line
Bore Diameter	128 mm
Number of Strokes	Four-stroke
Stroke Length	150 mm
Emission Standard	Euro 5 EEV with DOC + SCR
Compression Ratio	1 :16.82
Number of Valves	12 Intake + 12 Exhaust valves
Engine Displacement	11.580 Liter
Fuel Type	Diesel fuel
Engine Power/Rated Power	2000rpm /220 kW
Maximum Engine Torque	1500rpm /145 N.m
Engine Type	205 g/kW.h
Direction of Rotation:	Counter-clockwise



Figure 1. Engine Test Cell

TABLE 2. Test Results of Diesel Fuel Specification Used in Test

Property/Characteristic	Diesel fuel Test results	Test Method	Unit
Flash Point	61	EN ISO 2719	°C
Viscosity	4.1	EN ISO 3104	mm ² /s
Calorific Value	42570	-----	kJ/kg
Density	839	-----	kg/m ³

TABLE 3. Test Results of Biodiesel Specification Used in Test

Property/ Characteristic	Biodiesel Test results	Test Method	Unit
Flash Point	170	EN ISO 3679	°C
Viscosity	4.81	EN ISO 3104	mm ² /s
Calorific Value	33810	-----	kJ/kg
Density	880	-----	kg/m ³

2. 1. 4. Error and Uncertainty Analysis Errors and uncertainties in measurements may arise from the choice and calibration of instruments, variations in environmental conditions, and intrinsic constraints of the experimental procedures and observational techniques. Measurement uncertainties are generally classified into two categories: systematic errors, which originate from calibration deficiencies and bias, and random errors, which result from measurement repeatability and data scattering. The uncertainty of a measured variable (ΔX) is typically evaluated assuming a Gaussian distribution, where a range of $\pm 2\sigma$ corresponds to a 95% confidence interval for the observed values, as stated in Equation 1 (23).

$$\Delta X_i = \frac{2\sigma_i}{\bar{X}_i} \times 100 \tag{1}$$

In this context, X_i denotes an individual experimental reading, n is the total number of readings, and σ is the standard deviation. The uncertainties of the calculated parameters can be evaluated using Equation 3, where:

$$R = f(X_1, X_2, X_3, \dots, X_n) \tag{2}$$

$$\Delta R = \sqrt{\left[\left(\frac{\partial R}{\partial X_1} \Delta X_1 \right)^2 + \left(\frac{\partial R}{\partial X_2} \Delta X_2 \right)^2 + \left(\frac{\partial R}{\partial X_3} \Delta X_3 \right)^2 + \dots + \left(\frac{\partial R}{\partial X_n} \Delta X_n \right)^2 \right]} \tag{3}$$

where R is a function of the measured variables. Consequently, ΔR was calculated using the root mean square (RMS) of the errors associated with the measured parameters. The uncertainties inherent to the measurement instruments are summarized in Table 4.

TABLE 4. Accuracies of the Measurements

Measured Parameter	Measurement Device	Accuracy	Uncertainty
Rpm	Tachometer	1 rpm	± 1 rpm
Torque	Dynamometer	1 N.m	± 1 N.m
m_f	AVL -Fuel meter	0.1 kg/h	± 0.1 kg/h
HC, NOx	AVL DICOM4000	1 ppm	± 1 ppm
CO	AVL DICOM4000	0.01%	± 0.01 %
Opacity	AVL415 Smoke meter	0.1%	± 0.1 %

2. 2. Test Methodology and Procedure This study comprehensively assessed the effects of biodiesel blends on the operational performance and emission characteristics of a common-rail compression ignition (CI) engine. This study investigated the torque, power, and BSFC performance characteristics of the engine. The exhaust gas features examined included soot, CO, HC, and NOx, using two different base fuels and soybean biodiesel at volume percentages of B5%, B10%, and B15%, while varying the engine speed from 1000 to 2200 rpm in increments of 200 rpm. The investigations were implemented in full-load situations as well as four partial-load conditions: 25%, 50%, 75%, and 100%. The emission characteristics were studied for the partial load mode at three speeds: 1350, 1650, and 1950 rpm. Furthermore, to obtain better and more accurate results, every reading was duplicated three times, and the average measurements were used as the ultimate outcomes in the graphs.

3. RESULTS AND DISCUSSION

The test data for the base fuel and blended fuels at volumetric ratios of 5%, 10%, and 15% (indicated by the symbols B5, B10, and B15, respectively) are presented as follows:

3. 1. Brake Power

3. 1. 1. Interaction Impact of Fuel Type & Speed on Brake Power of Engine Owing to the correlation between power, torque, and speed under test conditions, the power variation also depends on the engine speed. Figure 2 shows the highest brake power, 219.1 kW which was obtained for the base fuel at a speed of 2000 rpm. The lowest brake power, 92.40 kW, was achieved at 1000 rpm for the base fuel. As depicted in the figure, brake power for the blended fuels increased with engine speed up to 1500 rpm, beyond which it declined at higher speeds. The relative power increased in blended fuels B5, B10, and B15 compared to that of the base fuel at 1000 rpm by +32.2%, +25.5%, and +20.4%, respectively. This relative increase showed a declining but positive trend up to 1500 rpm. The relative power changes for blended fuels B5, B10, and B15 compared to the base fuel at 1600 rpm were -10.0%, -40.0%, and -8.0%, whereas at 1800 rpm, they were -10.0%, -60.1%, and -4.2%, respectively. The magnitude of power reduction seen with the blended fuels, in relation to the calorific value of soybean biodiesel, depended on the particular composition of each fuel blend. The reduction in power associated with biodiesel’s lower calorific value is partly alleviated by its inherent characteristics—namely, greater oxygen content, higher cetane number, and increased density—which together help compensate for the resulting performance loss. The higher density and cetane rating of

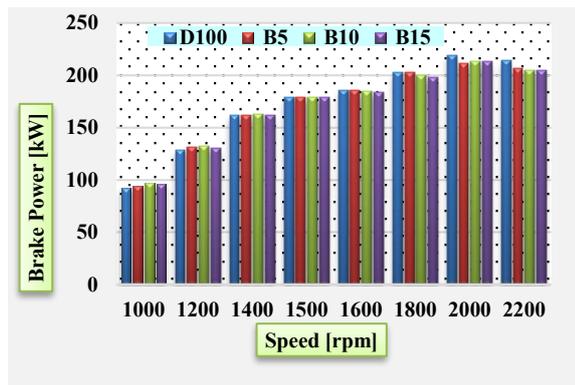


Figure 2. Effect of biodiesel on power at different speeds and full load

the blended fuels partially offset the impact of their reduced calorific value compared to the base diesel, which diminishes and smooths the variations in brake power across the different blends. The increased density of biodiesel allows a larger mass of fuel to enter the combustion chamber per injection, while its intrinsic oxygen content and higher cetane number enhance combustion at lower engine speeds, resulting in a corresponding improvement in engine power.

For the above reasons, the difference in brake power between the blended fuels was negligible at medium speeds, and their performance coincided. The biodiesel content in the blended fuels increased at medium and high speeds because of its lower calorific value which led to a decrease in the brake power at these operating points. At high speeds, such as 2000 and 2200 rpm, blended fuels B5, B10, and B15 showed relative power reductions of -3.30%, -2.60%, -2.90%, -3.20%, -4.10%, and -4.30%, respectively, compared with the base fuels. At higher speeds, near the maximum power, the influence of fuel properties on the brake power became more pronounced. At such speeds, the adverse effect of their low calorific value is more evident owing to ineffective atomization because of the high viscosity of the blended fuel and less time available for mixing with air, which, in turn, adversely affects the combustion quality. The trend of the curve indicates that the brake power decreased as the share of biodiesel increased compared to that of the base fuel, which is attributed to the lower energy content of biodiesel. The blended fuel B10 indicated the highest brake power among the tested fuels at low to medium speeds, at which the engine reached its peak torque, with an average relative increase of 2.2%, indicating the suitability of this fuel for use at low and medium speeds.

3. 1. 2. Interaction Effect of Fuel Type and Load on Engine Brake Power

The engine brake power is indicated at various loads, as shown in Figure 3. As shown in Figure 3, the brake power of the fuels examined in this study increased linearly with an increase in load

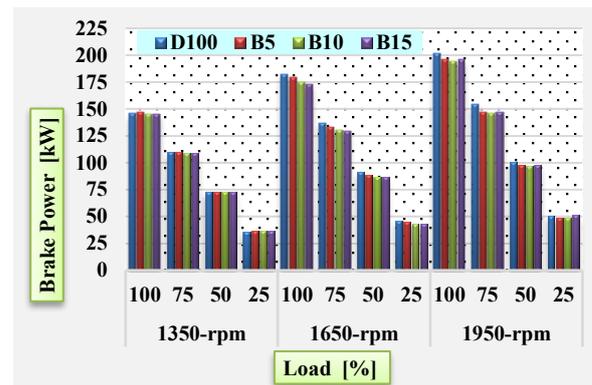


Figure 3. Effect of biodiesel on power at different speeds and partial load

from 25 to 100% at the aforementioned speeds. The relative changes in the brake power at full load and low speed for B5, B10, and B15 were -0.6%, +0.6%, and -0.4%, respectively, and the relative power drop was negligible.

The relative changes in brake power for B5, B10, and B15 at full load and intermediate speed were +2%, -2%, and -4.4%, respectively, whereas at high speed, they were +3%, -3%, and -4%, respectively. For B10 and B15 at maximum loads and intermediate and high speeds, the low heating value of biodiesel led to a relative decline in the brake power. A relative increase in power was observed for fuel B5 at partial loads and both intermediate and high speeds, which was attributed to the larger fuel mass injected per unit volume of biodiesel, owing to its high density and oxygen content.

3. 2. Engine Brake Torque

3. 2. 1. interaction Impact Fuel Type and Speed on Brake Torque

Brake torque is an engine performance property and is a function of the fuel type and engine speed. The relative increase in the brake torque of blended biodiesel fuels 5B, 10B, and 15B at 1000 rpm, according to Figure 4, was +2.30%, +5.20%, and +4.20%, respectively, compared with that of diesel. Engine torque showed a relative rise up to 1500 rpm, but beyond this point, it decreased at higher speeds in comparison to the torque achieved with the base diesel fuel. The maximum torque generated by the engine owing to volumetric efficiency was correlated with a speed of 1500 rpm, at which a relative decrease occurred. The relative torque changes at 1500 rpm for blended fuels 5B, 10B, and 15B with respect to pure diesel were -0.20%, +0.10%, and +0.12%, respectively, which were not significant changes. At low and moderate engine speeds, the inherent oxygen content and elevated density of biodiesel helped offset the drawbacks of its lower calorific value, promoting more efficient combustion of the fuel blend.

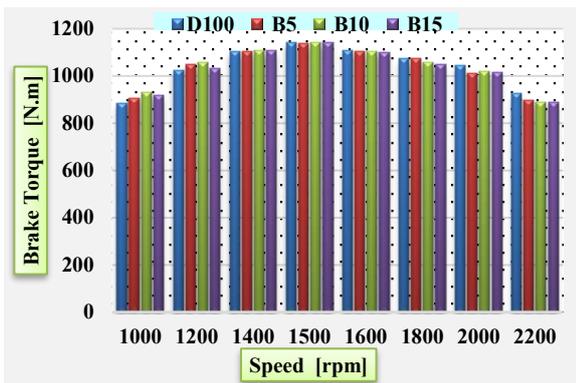


Figure 4. Impact of biodiesel on torque at different speeds

The relative decrease in torque of the blended fuels at high speeds of 2000 and 2200 rpm was -3.40%, -2.60%, -2.90%, -3.20%, -4.20%, and -4.30%, respectively. As the percentage of biodiesel increased at higher speeds, the amount of lost torque increased. The most important reasons for torque reduction at speeds higher than 1500 rpm, in addition to limited volumetric efficiency and increased frictional loss, are the low energy content and high viscosity of biodiesel. At these speeds, the high density of biodiesel changed the air-fuel ratio, and its high viscosity degraded the quality of fuel atomization and caused relative torque loss with respect to pure diesel fuel.

3. 2. 2. Interaction Impact Fuel Type and Load on Engine Brake Torque

Brake torque is a key engine function influenced by the physicochemical properties and percentage of biodiesel, rotational speed, and engine load. Figure 5 shows a graphical representation of the brake torque values for the four fuels at three speeds and four loads.

The variation in the relative brake torque at 1350 rpm for partial and complete loads was less than 1% for an increased biodiesel share in the blends. This increase was attributed to the presence of oxygen in the biodiesel.

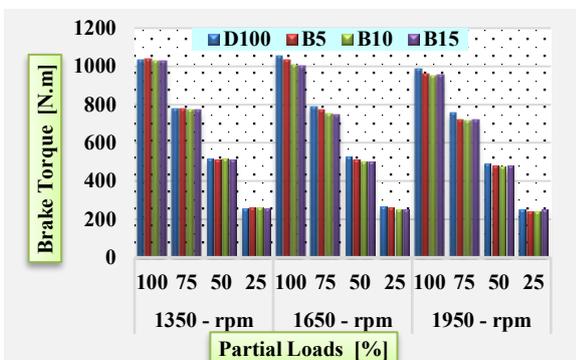


Figure 5. Impact of biodiesel on torque at varied speeds and loads

At the middle speed of 1650 rpm, the lowest torque disadvantages for B5, B10, and B15 were -0.2%, -4.5%, and -5.3%, respectively, under the full load conditions. At a 75% load, these decreases are -2.7%, -4.8%, and -5.3%; at a 50% load, they are -3%, 1.5%, and 2.3%; and at a 25% load, they are -1.1%, -4.5%, and -5%. The lower heating value of biodiesel, which is additionally associated with its high density, as well as the oxygen content in the biodiesel structure, partially compensates for its low calorific value and leads to a torque decrease at mid-range speeds. The power was reduced by a factor related to torque at a high-speed of 1950 rpm for the blended fuels of B5, B10, and B15 at full load by -2.7%, -3.5%, and -2.9%, respectively. This reduction for a 75% load is -4.8%, -6.5%, and -4.8%; for a 50% load it is -6.2%, -4.3%, and -6.2%; and for a 25% load it is -4.4%, 6.3%, and -4%. At higher engine speeds, torque exhibited a noticeable decline under both partial and full load conditions, primarily due to the combined effects of biodiesel's reduced energy content and its greater density relative to conventional diesel. Fuel-rich zones at high speeds and incomplete combustion caused a decline in torque only at this speed because of the direct injection of more fuel mass per unit volume, as biodiesel fuel is denser.

3. 3. Interaction of Fuel and Speed on BSFC

BSFC is widely used to compare the thermal and economic efficiencies of internal combustion engines. BSFC is typically associated with the performance of an engine at different loads or with various fuels at a given load. BSFC measures how efficiently an engine converts fuel into usable power, indicating the amount of fuel required to generate a given brake power. It provides a comparative basis for evaluating biodiesel against conventional fuels in terms of energy efficiency. It is determined by relating the mass flux of the fuel through the cylinder to the brake-power output of the engine. As shown in Figure 6, brake-specific fuel consumption (BSFC) decreases at low and moderate engine speeds, while it rises at higher speeds. The BSFC at 1000 and 1200 rpm with B5, B10, and B15 changed by -1.7%, -0.4%, +0.6%, and -1.7%, -1.4%, and -1.1% compared to the base fuel, respectively. The differences in BSFC from the base fuel for biodiesel blends B5, B10, and B15 at medium speed were -0.34%, +0.34%, and +0.15%, respectively. At high speeds, the values were +3.2%, +0.2%, and +2.1%, respectively. The BSFC characteristics depend directly on the fuel density and inversely on the fuel calorific value. Fuel blends featuring lower density combined with higher calorific values achieved the lowest BSFC when operated at identical loads.

The elevated BSFC observed with biodiesel, relative to the base fuel, can be attributed to its lower energy content. The reduced calorific value of the blend

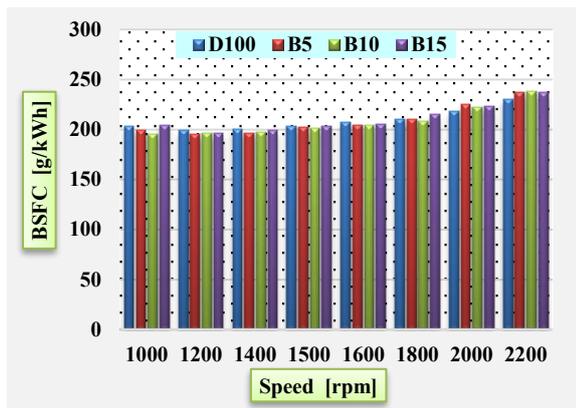


Figure 6. The effect of biodiesel on BSFC feature

consequently resulted in increased specific fuel consumption. Due to its higher density, biodiesel requires greater fuel volumes to generate an equivalent level of engine power. This decline occurred because the fuel contained less energy than that of diesel. Biodiesel fuel benefits from its high density and oxygen content, which improve combustion, and high cetane number, which counters the low calorific value, resulting in a reduced BSFC at low speeds. When operating at medium speeds, biodiesel produced BSFC values that were nearly equal to those of diesel fuel. At high speeds, the low calorific value and high viscosity of the biodiesel fuel resulted in poor atomization, which led to an increased BSFC.

3. 4. Effect of Biodiesel on Soot Emission Rate

Heywood (24) in his book "Internal Combustion Fundamentals," defined soot as a mixture of large solid particles and small liquid droplets in exhaust gases, mainly comprising carbon soot, unburned organic matter, and sulfate compounds. The non-uniform charge distribution in the cylinder creates areas where the fuel mixture is rich but lacks sufficient oxygen and experiences incomplete vaporization. In these regions, some of the fuel pyrolyzed, resulting in primary soot particles. These nuclei became larger particles when carbon and organic molecules were added. Because of the oxygen present in the fuel-rich portion of the flame, oxidation activities can produce carbon dioxide. Soot is created by incomplete combustion processes at locations far from the flame and with little oxygen. Soot formation is caused by incomplete combustion, poor fuel and air mixing, high engine load, low engine speed, aromatic compounds, and sulfur in fuel.

To reduce soot, a reasonable and possible fuel-air mixture quality, fuel/air ratio, and combustion condition, high injection pressure, and low-sulfur fuel are used. Moreover, soot production depends on the fuel type, biodiesel content, and engine load. Figure 7 illustrates the evolution of carbon for four distinct fuels under three engine speed conditions. The blended fuels (D100, B5,

B10, and B15) emit full-load particulate emissions of 0.000, 0.000, 0.003, 0.005, and 0.007 g/kWh at average speed; 0.000, 0.008, 0.006, and 0.008 g/kWh at high speed; and 0.000, 0.022, 0.026, and 0.023 g/kWh at low speed. The soot emissions of D100 and its blends were 0.001, 0.001, 0.003, and 0.017 g/kWh at low load; 0.001, 0.001, 0.013, and 0.026 g/kWh at mid load; and 0.001, 0.051, 0.068, and 0.057 g/kWh at full load, all in the 25% load range.

The exhaust gas flow from vehicles using biodiesel produced more carbon particulates because biodiesel has higher density and viscosity. The atomization of viscous biodiesel is poor, resulting in large fuel droplets coexisting within the cylinder. This condition slows the mixing of fuel and air, ultimately leading to the formation of a "fuel-rich" mixture zone. Biodiesel also has a high vaporization temperature and can only partially vaporize under low-load and low-temperature conditions. At low and mid speeds and in part-load situations, the air-fuel ratio is higher, which leads to a lean mixture. The increase in the oxygen content in the biodiesel molecule increases the combustion efficiency, and if sufficient time for soot oxidation is available under these conditions, the increase in soot emissions can be small compared with that in diesel.

The experimental findings indicate that, while overall fuel consumption declined with higher biodiesel blend ratios, the rate of soot formation increased under identical engine conditions at both light and full loads, particularly at low and medium speeds. This effect is attributed to the higher viscosity of biodiesel, which impairs atomization and produces locally rich fuel zones near the injection spray, resulting in comparatively higher soot emissions than those observed with conventional diesel. The higher density of biodiesel at increased velocities complicates the air intake, elongating the zones of denser fuel and shortening the time available for soot oxidation due to faster processing. However, the quantity of oxygen present during fuel combustion is insufficient, resulting in a greater discharge of soot than the base fuel.

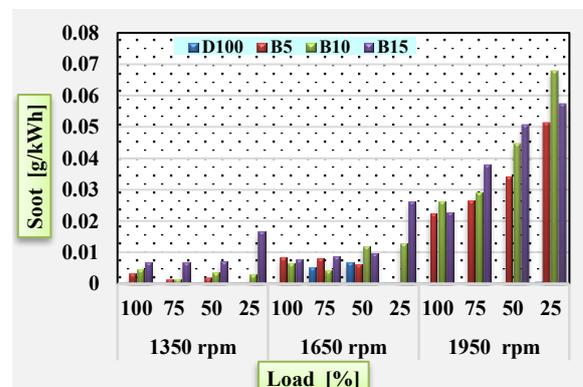


Figure 7. Effect of Biodiesel in Emission Test Modes on Soot

3. 5. Effect of Biodiesel on Carbon Monoxide

Carbon monoxide emissions largely arise from incomplete combustion. In regions where the air–fuel ratio is fuel-rich ($\lambda < 1$), the limited availability of oxygen prevents the full conversion of carbon in the fuel to carbon dioxide (CO_2). Therefore, a portion of the carbon remained unoxidized and was released as CO emissions. As a diesel engine is always under lean combustion conditions (excess air; $\lambda > 1$), relatively little carbon monoxide is formed. High combustion temperatures enable the conversion of carbon monoxide to carbon dioxide through oxidation; however, low exhaust gas temperatures prevent this conversion.

The pollutant is formed because of two factors: the slow fuel vaporization process and the creation of a rich mixture during low-load and cold-start engine operations. In addition, at low speeds, owing to the sufficient time for fuel-air mixing, the amount of CO emissions decreased as the speed decreased. The maximum amount of carbon monoxide emissions for blended and base fuels was registered under no-load conditions. The high viscosity, poor atomization, and incomplete vaporization of biodiesel fuel cause local incomplete combustion and the formation of carbon monoxide emissions. As shown in Figure 8, with an increase in the load, the amount of carbon monoxide emissions for all fuels decreased owing to the high combustion temperatures at full load.

As illustrated in Figure 8, the relative changes in carbon monoxide emissions for blended fuels B5, B10, and B15, compared to the base fuel at full load and at low, middle, and high speeds, were (-0.13%, -0.02%, +0.37%), (+2.5%, +7.5%, +8.5%), and (+5%, +5.5%, +4.5%), respectively. For blended fuels at a partial load of 50% and low, middle, and high speeds, the relative changes in this pollutant were (+3.6%, +1.1%, +3.6%), (+22%, +16%, +15%), and (+7.5%, +5.2%, +6.7%), respectively. At a partial load of 25% and low, middle, and high speeds, the relative changes for blended fuels

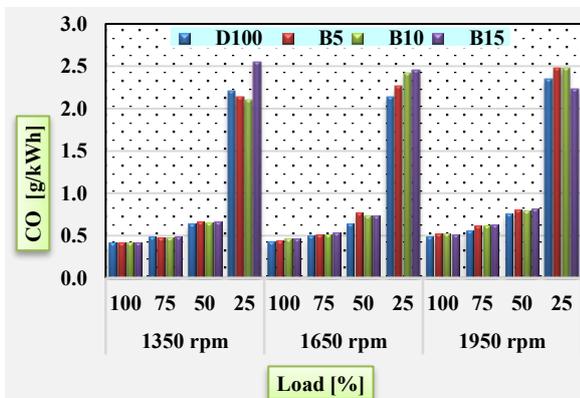


Figure 8. Effect of Biodiesel in Emission Test Modes on Carbon Monoxide

B5, B10, and B15 were (-3%, -4.4%, +15.5%), (+7.5%, +13.2%, +14.5%), and (+7.5%, +5.8%, -4.9%), respectively. For the blended fuels, at all speeds, the maximum carbon monoxide emissions were at a 25% partial load and the minimum at full load. The high combustion temperature and increased oxygen content in the biodiesel fuel were more effective at high loads because of the higher air-to-fuel ratio. At partial loads and low speeds, the increased air-to-fuel ratio resulted in excess air that reduced the combustion temperature, caused incomplete vaporization of the biodiesel fuel, and decreased the reaction rate of carbon monoxide oxidation to carbon dioxide. Specifically, increasing the proportion of biodiesel in the fuel blend results in elevated emissions of this pollutant. At full load and high speed, with an increase in the combustion temperature owing to improved combustion, the amount of this pollutant decreased. Previous investigations have demonstrated that carbon monoxide formation is primarily linked to incomplete combustion resulting from a low air-to-fuel ratio. Additional contributing factors include the physicochemical properties of the fuel, injection parameters, engine load, low operating temperatures, and insufficient residence time for complete oxidation. Elevated CO emissions indicate that a portion of the fuel's chemical energy is not effectively converted into useful work by the engine (25, 26).

3. 6. Effect of Biodiesel Fuel on Unburned Hydrocarbon Emissions

HC emissions are primarily the result of incomplete combustion. If a fraction of the fuel is not oxidized in the combustion chamber, it is classified as an unburned hydrocarbon (UHC). The lowest combustion chamber loads produced the lowest temperatures, which prevented sufficient fuel oxidation. If the fuel and air are incorrectly mixed and create fuel-lean/fuel-rich zones, and if the biodiesel fuel is of poorer quality than diesel fuel owing to its higher viscosity, all these factors lead to incomplete combustion, which causes an increase in this pollutant. Fuel features such as viscosity, density, and engine operating conditions are effective in reducing this pollutant level. High-viscosity biodiesel fuels also allow the formation of large fuel droplets. If the fuel is not completely atomized, it will not burn. This process results in excess hydrocarbon production. From Figure 9, it can be observed that the increase in this pollutant for blends B5, B10, and B15 compared to pure diesel fuel at full load and low, mid, and high speeds were (-1.3%, +20%, +81%); (+122%, +97%, 171%); and (-4.6%, -13.7%, +23.4%), respectively. The changes in this pollutant at a partial load of 25% and low, middle, and high speeds for the B5, B10, and B15 blends compared to the base fuel were (+23%, +12.6%, +57.5%), (+48%, +35.8%, +94.6%), and (-16.9%, -16.9%, +22.3%), respectively. The viscosity of biodiesel fuel discharges

large fuel droplets, resulting in inadequate atomization at partial loads and low speeds. These factors suggest that the high boiling point of biodiesel, coupled with relatively low combustion chamber temperatures, can prevent complete fuel vaporization, ultimately resulting in incomplete combustion.

The elevated density of biodiesel promotes the formation of fuel-rich regions, leading to incomplete combustion under full-load conditions. Additionally, the available oxidation time is reduced. While the inherent oxygen content of biodiesel aids the combustion process, fuel-rich zones still result in an increase in unburned hydrocarbon emissions.

3. 7. Effect of Biodiesel-Blended Fuel on NOx Emissions

In general, the reduction in fuel injection at partial loads causes the combustion temperature to be low, leading to a reduction in the generation of NOx. As a result of the NOx creation process, which is heavily reliant on temperature, the reactions involved in NOx formation proceed slowly at low temperatures. At low engine loads, the high viscosity of biodiesel impairs proper fuel-air mixing, leading to localized high-temperature regions in the combustion chamber and, consequently, elevated NOx formation. A decrease in the combustion temperature at partial loads reduces the NOx formation. The chemical composition of biodiesel increases its oxygen content. Such an increase causes more complete combustion at low temperatures and reduces the NOx formation at high temperatures. Biodiesel contains higher oxygen content in its chemical structure than fossil fuels, which results in elevated combustion temperatures when the biodiesel concentration increases, thus producing more nitrogen oxides (NOx).

The two-stage injection method includes pilot injection, which shortens the ignition delay and controls

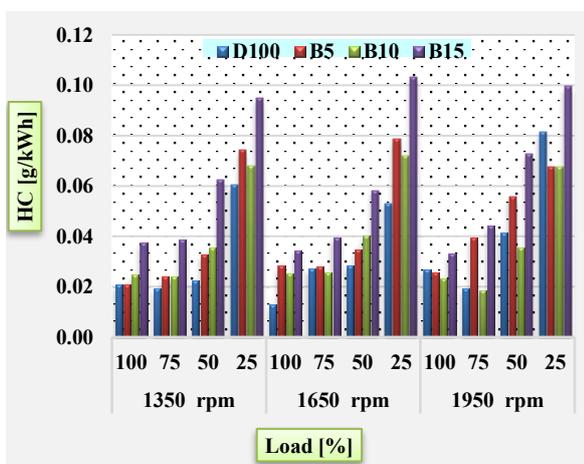


Figure 9. Effect of Biodiesel in Emission Test Modes on Unburned Hydrocarbons

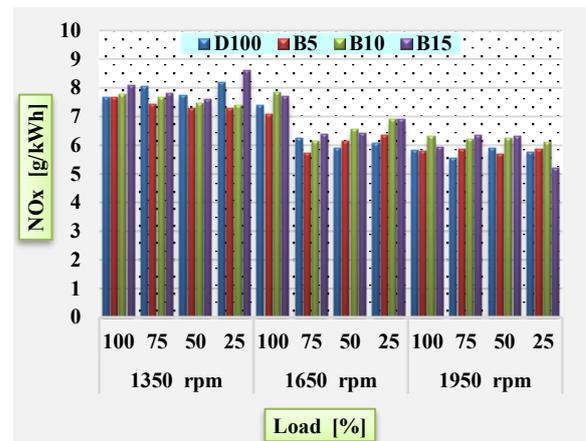


Figure 10. Effect of Biodiesel in Emission Test Modes on NOx

the initial combustion temperature, and main injection, which manages the temperature levels to prevent the formation of NOx. Rising combustion temperatures led to a corresponding increase in nitrogen oxide (NOx) emissions. Figure 10 illustrates the relative increase in NOx emissions for blended fuels B5, B10, and B15 compared to pure diesel at full load across low, middle, and high speeds, with values of (-0.27%, +1.34%, +5.31%), (-4.40%, +6.25%, +4.16%), and (-0.71%, +8.12%, +1.19%), respectively.

At low speeds and partial loads, the NOx emissions were reduced because of the low temperature. Because of the enhanced oxygen content of the blended fuels, the combustion temperature increased at the maximum load and low speed, which in turn resulted in more NOx emissions. Modifying the temperature and pressure conditions for NOx formation increased the amount of NOx at an intermediate speed. At higher engine speeds, the reduced residence time of gases in the combustion chamber contributed to a decrease in NOx emissions. Nevertheless, the high temperature of the combustion chamber allows NOx pollutants to form, which are present in greater quantities than the base fuel.

Under full-load conditions at low and medium engine speeds, incorporating soybean biodiesel markedly elevated NOx emissions, primarily due to higher peak combustion pressures and temperatures, as well as a shortened ignition delay. The combustion process was further enhanced by the intrinsic oxygen content of biodiesel, which promotes more complete oxidation. This procedure resulted in more thorough burning at lower temperatures. Furthermore, at high temperatures, the NOx formation decreased. In addition, an increase in the biodiesel percentage because of its high oxygen content increased the combustion temperature and produced more NOx. Multistage injection strategies, such as pilot and main injections, significantly reduce ignition delay and control the temperature at the beginning and main

stages of combustion, which also reduces NOx. When the injection pressure is higher, the atomization of the fuel is finer. This improves combustion, which increases the combustion temperature. Consequently, more NOx was produced.

3. 8. Effect of Biodiesel-Blended Fuel on Pollutants

Table 5 presents the total emissions of HC, CO, NO_x, and soot measured over the 13-mode steady-state test cycle. The data in Table 5, together with Figure 11, show that biodiesel–diesel blends emitted higher levels of these pollutants than neat diesel; however, all values remained within the regulatory limits of the Euro 5 environmental standard. The units are expressed in g/kWh.

The higher viscosity of soybean biodiesel compared to diesel fuel causes poor spray atomization, resulting in poor combustion efficiency and higher pollutant emissions. The engine produced elevated emissions because it was operated without biodiesel optimization. The combustion process of biodiesel operates more efficiently because it contains built-in oxygen, has a high cetane rating, and has a short ignition delay, which minimizes some biodiesel-related negative effects.

At the conclusion of this section, Table 6 presents a summary of the results from both the studies included in the literature review in the introduction and the current study.

TABLE 5. Engine Emission Components in the ESC Test

Emissions	D100 g/kWh	B5 g/kWh	B10 g/kWh	B15 g/kWh	Euro V
CO	0.17	0.23	0.210	0.312	0.46
HC	0.741	0.912	0.857	0.861	1.50
NOx	6.639	6.544	7.029	7.016	2.00
Soot	0.002	0.013	0.015	0.017	0.02

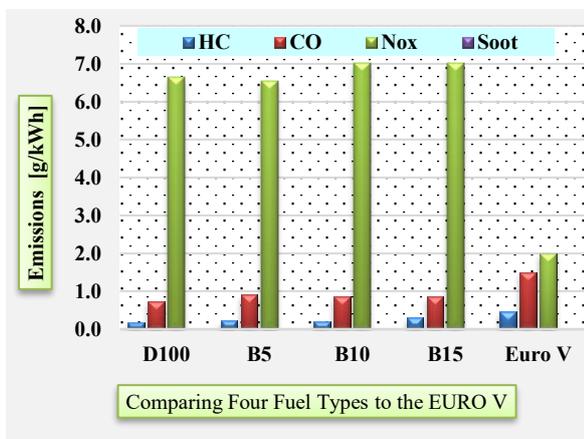


Figure 11. Comparison of Emission Results for Four Fuel Types with EURO V Standard

TABLE 6. Summary of Findings and Comparison from the Literature Review and present study

Author(s)	Key Findings
Wang et al. [2]	PN ↓; geometric mean diameter unchanged; PM ↓ with load/speed ↑
Ho et al. [3]	BSFC ↓, BTE ↑; CO ↓; PN ↓; NOx ↓ with ethanol (cooling effect)
Kim et al. [4]	Viscosity ↑ → delayed injection; droplet size ↓ → CO ₂ ↓; NOx ↑, PM ↓
Chen and Wu [5]	PN ↓, PM ↓; oxygen esters ↓ NOx (anti-knock); soot ↓
Lapuerta, et al. [6]	Power ~ diesel (partial load); power ↓ at full load; CO, HC, PM ↓
Xue et al. [7]	LCV ↓, BSFC ↑; power ↓; blend ratio/additives matter; inline pumps limit injection strategies
Mostafavi et al. [8]	η_{th} ↓; latent heat ↑; air–fuel temp ↓ → misfires, flame quench
Eremeeva et al. [9]	Biodiesel met fuel quality; reduced harmful emissions
Özener et al. [10]	Torque ↓, BSFC ↑; CO & HC ↓ (28–46%); NOx & CO ₂ ↑; ignition delay ↓
Vellaiyan et al. [11]	Smoke, CO, HC ↓; NOx ~ unchanged; SFC ↓ (≤10% water)
Fayad [12]	CO, HC ↓; NOx & smoke ↑ at certain timings/pressures
Kim et al. [13]	Cetane ↑, oxygen ↑ → ignition improved; injection pressure ↑ → atomization ↑ but NOx ↑
Kadam et al. [14]	B60GNP100 → BSFC ↓ (12.58%), BTE ↑ (27.13%)
Nguyen et al. [15]	Power ↓, BSFC ↑, NOx ↑; smoke, HC, CO ↓ vs. gasoline
Talesh et al. [16]	Unsaturated FA → faster burn, start time ↓; saturated FA little effect
Jafarmadar et al. [17]	B15 → PM ↓; B20/B30 → BSFC & NOx ↑; quarter-load → NOx & PM ↓
Jafarmadar et al. [18]	Soot & NOx ↓ simultaneously; soot–NOx trade-off mitigated
Youssef et al. [19] & Jafarmadar et al. [20]	Fuel use ↓ 5.9%; BTE ↑ 9.6%; NOx ↓ 20.5%
Rosiane et al. [21]	BTE ↑ 56.08%; BSFC ↓ 18.33%; CO ↓ 30%
Khujamberdiev and Che [22]	CO ↓ 30%; HC ↓ 21.5%; CO ₂ ↑ 15%; NOx ↓ 20% at high speed
Present Study	<ul style="list-style-type: none"> - Power/Torque: slight ↑ at low–mid speeds; drop above 1500 rpm (viscosity & poor atomization). - BSFC: ↓ 1–4% at low–mid speeds; ↑ 1–3.5% at high speeds. - Soot: small ↑ at mid loads, sharp ↑ at high loads. - CO: max at 25% load, min at full load. - UHC: ↑ at low speeds & full load (fuel-rich zones). - NOx: ↓ at low load; ↑ at full load due to higher temps/oxygen; partly ↓ at high rpm.

4. CONCLUSION

The operational performance and emission characteristics of a six-cylinder OM355 common-rail diesel engine were assessed using soybean biodiesel–diesel blends (B5, B10, and B15) under both full- and partial-load conditions. The results show that at low to medium engine speeds, the higher density and oxygen content of biodiesel partially offset its lower heating value, leading to slight improvements in power and torque and a 1–4% reduction in BSFC. However, at speeds above 1500 rpm, the high viscosity and boiling point of biodiesel caused poor atomization and incomplete evaporation, resulting in decreased power and torque as well as a 1–3.5% increase in BSFC.

Emission analysis indicated that biodiesel blends slightly increased soot and CO emissions at low speeds due to incomplete vaporization but facilitated better combustion and soot oxidation at partial loads. At high speeds and full loads, soot emissions rose significantly because of fuel-rich zones. CO emissions peaked at 25% partial load, while the lowest values were recorded at full load. UHC emissions increased at low speeds and full load, mainly due to poor vaporization and the formation of fuel-rich areas. NOx emissions were reduced at low loads owing to lower combustion temperatures but increased under full load because of higher peak temperatures and pressures; at high speeds, shorter residence times limited NOx formation.

Overall, soybean biodiesel blends are compatible with common-rail diesel engines without structural changes, though penalties in BSFC, soot, and NOx emissions become evident at high-speed and high-load operation.

The authors suggested specific nonstructural modifications for soybean biodiesel properties to address these limitations, including preheating the fuel, raising rail pressure, shortening injection time, adding additives, and adjusting ECU settings. These performance optimization methods reduce combustion-related negative impacts while creating better engine operation stability. Biodiesel blends up to B15 demonstrate effective compatibility with Euro 5+ compliant diesel engines for complete fuel substitutions.

Future biodiesel research must investigate the complete range of engine performance and emission output variations that occur when the biodiesel concentration in the base fuel progresses from B20 to B100. Evaluating the effects of biodiesel on engine longevity and component wear is essential, alongside examining its compatibility with advanced emission control systems, including Selective Catalytic Reduction (SCR) and Diesel Particulate Filters (DPF), to effectively reduce NOx, soot, and other regulated pollutants.

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**Persian Abstract****چکیده**

در این تحقیق تأثیر استفاده از سوخت های ترکیبی بیودیزل سویا/دیزل با نسبت های حجمی B₁₀، B₁₅ و B₂₀ را بر مشخصه های عملکردی و آلایندگی یک موتور دیزل تجاری ریل مشترک (OM350) بررسی شد. نتایج نشان داد که توان و گشتاور ترمزی در سرعت های پایین تا متوسط، در محدوده ۱۰۰۰ تا ۱۵۰۰ دور در دقیقه، نسبت به سوخت دیزل معمولی ۰.۵ تا ۵ درصد افزایش داشته، اما در سرعت های بالا، به ویژه در محدوده ۱۸۰۰ تا ۲۲۰۰ دور در دقیقه، کاهش بین ۱ تا ۴ درصد در مقایسه با سوخت دیزل معمولی مشاهده شد. مشخصه مصرف سوخت ویژه ترمزی، در سرعت های پایین و متوسط، به ویژه بین ۱۰۰۰ تا ۱۵۰۰ دور در دقیقه، به دلیل کاهش محتوای انرژی ناشی از استفاده از بیودیزل سویا، ۴ تا ۱ درصد کاهش یافت. با این حال، در سرعت های بالا در محدوده ۱۸۰۰ تا ۲۲۰۰ دور در دقیقه، این مشخصه افزایشی بین ۱ تا ۳/۵ درصد داشت. علاوه بر این، نتایج آزمون آلایندگی نشان داد که انتشار آلاینده ها از سوخت های ترکیبی به دلیل عدم اعمال اصلاحات در موتور، نسبت به سوخت دیزل معمولی به طور قابل توجهی افزایش یافته است. طبق یافته های آزمون حالت پایا، با وجود افزایش انتشار آلاینده های سوخت های ترکیبی، اما میزان انتشار آلاینده های مذکور به جز آلاینده ناکس، در محدوده استاندارد یورو ۵ باقی ماند. با توجه به اینکه موتور دیزل در سرعت های متوسط، که محدوده بیشینه گشتاور خود می باشد، به طور بهینه عمل می کند، استفاده از مخلوط های بیودیزل B₁₀، B₁₅ و B₂₀ با توجه به ویژگی های عملکردی موتور مناسب قابل قبول است. برای کاهش اثرات انتشار آلایندگی سوخت بیودیزل، اصلاحات مختلفی از جمله پیش گرمایش سوخت، افزایش فشار ریل سوخت، کاهش زمان پاشش، استفاده از افزودنی ها و تنظیم واحد کنترل الکترونیکی موتور بر اساس ویژگی های بیودیزل سویا می توان از این سوخت به عنوان یک جایگزین عملی در موتورهای دیزلی استفاده کرد.