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Injection Pressure Optimization for Non-edible Biodiesel Blends in CRDI Engines: A Comparative Study

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Abstract

The growing demand for clean and sustainable energy has increased interest in biodiesel produced from non-edible oil sources. These fuels are renewable, biodegradable, and do not compete with food resources. However, the effective use of biodiesel blends in modern diesel engines requires proper control of fuel injection parameters, particularly injection pressure. In common rail direct injection (CRDI) engines, injection pressure strongly influences spray formation, air–fuel mixing, combustion behaviour, and exhaust emissions. Therefore, identifying an optimum injection pressure is essential for achieving better engine performance and lower emissions when non-edible biodiesel blends are used. In this study, a detailed experimental investigation was conducted to examine the effect of injection pressure on the performance, combustion, and emission characteristics of non-edible biodiesel–diesel blends in a CRDI engine. The engine was operated at a constant speed under different load conditions, while injection pressure was varied over a selected range suitable for CRDI operation. Key performance parameters such as brake thermal efficiency and brake specific fuel consumption were evaluated. Combustion characteristics were analyzed using in-cylinder pressure and heat release rate data. Exhaust emissions, including nitrogen oxides, carbon monoxide, unburned hydrocarbons, and smoke opacity, were also measured to assess environmental impact. The experimental results indicated that increasing injection pressure improved fuel atomization and enhanced combustion quality for biodiesel blends up to an optimum level. At this optimized injection pressure, brake thermal efficiency showed noticeable improvement, while brake specific fuel consumption decreased compared to lower injection pressures. In addition, carbon monoxide, hydrocarbon, and smoke emissions were significantly reduced due to better air–fuel mixing and more complete combustion. A moderate increase in nitrogen oxide emissions was observed at higher injection pressures, mainly due to elevated combustion temperatures. Overall, the study demonstrates that proper injection pressure optimization can effectively improve the performance and emission behaviour of non-edible biodiesel blends in CRDI engines, supporting their practical application without the need for major engine modifications.

Keywords: Combustion characteristics, CRDI engine, exhaust emissions, injection pressure optimization, non-edible biodiesel

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INTRODUCTION

The growing demand for energy, combined with strict environmental regulations, has placed significant pressure on the transportation and power generation sectors to reduce their dependence on fossil fuels. Diesel engines continue to play a vital role in these sectors due to their high thermal efficiency, reliability, and long service life. However, the widespread use of diesel fuel is closely linked to increased emissions of greenhouse gases and harmful pollutants such as nitrogen oxides, carbon monoxide, unburned hydrocarbons, and particulate matter [1-5]. These concerns have accelerated research efforts toward identifying cleaner and renewable alternative fuels. Biodiesel has emerged as a suitable alternative to conventional diesel fuel because it is renewable, biodegradable, and capable of reducing net carbon emissions. Biodiesel produced from non-edible oil sources is particularly attractive, as it avoids competition with food supplies and makes use of underutilized natural resources [6-9]. These non-edible oils can be cultivated on marginal land and often require lower agricultural inputs, making them environmentally and economically beneficial. In addition, biodiesel contains oxygen within its molecular structure, which supports improved combustion and can lead to lower emissions of incomplete combustion products [10-14].

The successful use of biodiesel in diesel engines depends not only on fuel selection but also on proper engine parameter optimization. Biodiesel generally has higher viscosity and density than petroleum diesel, which can affect spray formation and fuel atomization during injection. As a result, injection system parameters must be carefully controlled to ensure efficient combustion. Modern common rail direct injection (CRDI) engines provide greater flexibility than conventional injection systems, as they allow independent control of injection pressure, timing, and duration [15-18]. This flexibility makes CRDI engines well suited for operating with biodiesel–diesel blends. Injection pressure is one of the most influential parameters in CRDI engines, as it directly affects droplet size, spray penetration, and air–fuel mixing. Higher injection pressure generally produces finer fuel droplets, which enhances evaporation and promotes more uniform combustion. This can improve engine performance and reduce emissions such as carbon monoxide, hydrocarbons, and smoke [19-21].

However, excessively high injection pressure can increase in-cylinder temperature, leading to higher nitrogen oxide emissions and increased mechanical stress on the injection system. Therefore, identifying an optimum injection pressure is essential for achieving a balanced trade-off between performance improvement and emission control. Although several studies have examined biodiesel operation in CRDI engines, comprehensive comparative investigations focusing on injection pressure optimization for non-edible biodiesel blends remain limited [22-25]. Most existing studies concentrate on a single fuel or fixed injection conditions, leaving a gap in understanding the combined influence of injection pressure and biodiesel blend composition. The present study addresses this gap by systematically analyzing the effect of varying injection pressure on the performance, combustion, and emission characteristics of non-edible biodiesel blends in a CRDI engine. The findings of this work are expected to contribute to the effective utilization of non-edible biodiesel fuels in modern diesel engines and support the transition toward cleaner energy systems [26-29].

MATERIALS AND METHODS

This chapter presents a detailed description of the materials used, biodiesel preparation, fuel characterization, engine setup, injection pressure selection, experimental procedure, and uncertainty analysis. The methodology was designed to ensure accurate comparison between diesel and non-edible biodiesel blends under varying injection pressure conditions in a CRDI engine.

Selection of Non-edible Biodiesel and Blend Preparation

A non-edible oil source was selected for biodiesel production due to its availability, low economic value, and suitability for sustainable fuel development. The use of non-edible oil avoids competition with food resources and supports environmentally responsible fuel production. Biodiesel was produced through a standard transesterification process, where the raw oil was reacted with methanol in the presence of a catalyst under controlled temperature and stirring conditions. After completion of the reaction, glycerol was separated, and the biodiesel was repeatedly washed with warm water to remove residual catalyst, soap, and unreacted alcohol. The washed biodiesel was then dried to eliminate moisture content. The final product was filtered and stored in airtight containers before blending. Biodiesel–diesel blends were prepared on a volume basis to ensure uniform mixing and stable engine operation. A moderate blend ratio was selected to balance fuel properties and engine compatibility while allowing effective comparison with neat diesel fuel.

Fuel Properties Analysis

Fuel properties have a strong influence on the fuel injection process, combustion quality, and exhaust emissions in CRDI engines. Compared to conventional diesel, biodiesel usually has higher density and viscosity, which can affect fuel spray breakup and atomization inside the combustion chamber. To understand these effects, the important physicochemical properties of diesel and the non-edible biodiesel blend were measured using standard testing methods. The measured properties include density, kinematic viscosity, calorific value, flash point, and cetane index. These properties were selected because they directly influence ignition behavior, fuel–air mixing, and combustion efficiency. The measured values were compared with the limits specified by ASTM standards to ensure that the prepared biodiesel blend is suitable for engine operation. As presented in Table 1, the biodiesel blend shows slightly higher density and viscosity than diesel, along with a lower calorific value. At the same time, it exhibits a higher flash point and cetane index, which are beneficial for fuel safety and ignition quality. The information provided in Table 1 confirms that the non-edible biodiesel blend meets standard fuel requirements and can be safely used in a CRDI engine. These differences in fuel properties also help explain the variations observed in engine performance and emission characteristics during the injection pressure optimization study.

CRDI Engine Test Setup

The experimental study was conducted using a water-cooled, single-cylinder diesel engine fitted with a common rail direct injection (CRDI) system. The CRDI system allows precise and independent control of injection pressure, which makes it suitable for evaluating the influence of injection pressure on engine performance and emission characteristics. The engine was coupled to an eddy current dynamometer to regulate the load and measure the output torque. Fuel consumption was determined using a burette and stopwatch method to ensure accurate measurement of fuel flow rate. In-cylinder pressure data were obtained using a piezoelectric pressure sensor mounted on the cylinder head, while a crank angle encoder was employed to record crank angle–based combustion information. Exhaust emissions, including gaseous pollutants, were measured using a calibrated gas analyzer, and smoke opacity was measured using a standard smoke meter. The complete experimental arrangement used for this study is illustrated in Figure 1, which presents the schematic diagram of the CRDI engine test setup.

Before starting the experiments, the engine was operated for a sufficient period to reach stable operating conditions. All tests were conducted at a constant engine speed of 1500 rpm to ensure consistent comparison between different test cases. Engine load was varied using the eddy current dynamometer, while injection pressure was systematically adjusted for each test fuel. For every operating condition, performance parameters such as brake power, fuel consumption, and exhaust gas temperature were measured and recorded. Cylinder pressure data were collected over several consecutive engine cycles and averaged to minimize the effect of cycle-to-cycle variations. Exhaust emission measurements were repeated three times for each operating condition, and the mean values were reported to improve the accuracy and reliability of the results. The main technical details of the CRDI engine and test equipment used in this study are summarized in Table 2.

Table 1. Fuel properties of diesel and non-edible biodiesel blends.

Property	Diesel	Biodiesel blend (B20)	Test method
Density at 15 °C (kg/m³)	830	845	ASTM D4052
Kinematic viscosity at 40 °C (mm²/s)	2.6	3.2	ASTM D445
Calorific value (MJ/kg)	43.0	40.2	ASTM D240
Flash point (°C)	56	128	ASTM D93
Cetane index	48	52	ASTM D976

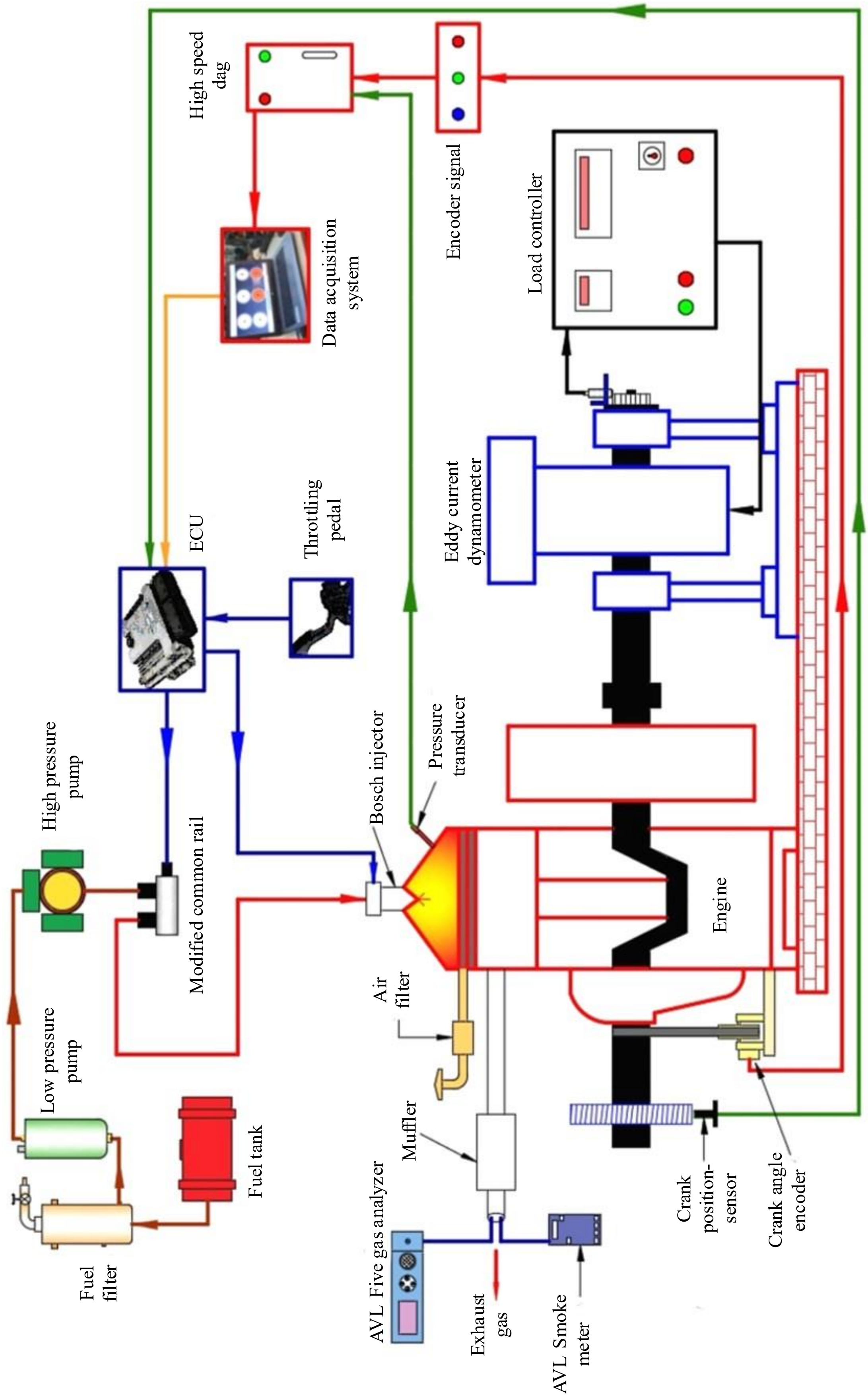


Figure 1. Schematic diagram of CRDI engine setup.

Table 2. Specifications of the CRDI engine.

Parameter	Specification
Engine type	Single-cylinder, 4-stroke, CRDI diesel engine
Cooling system	Water-cooled
Rated power	3.5–5.0 kW
Rated speed	1500 rpm
Bore × Stroke	87.5 mm × 110 mm
Compression ratio	17.5:1
Injection system	Common rail direct injection
Injection timing	Constant
Dynamometer	Eddy current
Data acquisition	Computer-based system

Selection of Injection Pressure Range

Injection pressure was selected as the key control parameter due to its direct influence on fuel spray characteristics, droplet size, and air–fuel mixing. A suitable range of injection pressures was chosen to represent low, medium, and high-pressure operation within the safe limits of the CRDI system. The selected pressure range was based on engine manufacturer guidelines and previous experimental studies. Injection timing was maintained constant throughout the experiments to isolate the effect of injection pressure alone. This approach ensured that observed variations in performance, combustion, and emissions were primarily due to changes in injection pressure.

INJECTION PRESSURE OPTIMIZATION STRATEGY

Injection pressure is one of the most important parameters in common rail direct injection (CRDI) engines because it directly affects fuel spray formation, droplet size, air–fuel mixing, and combustion efficiency. When using non-edible biodiesel blends, optimizing injection pressure becomes even more crucial due to their higher viscosity and density compared to conventional diesel. Proper injection pressure ensures better atomization, which improves combustion and reduces emissions. Higher injection pressure generally produces finer fuel droplets. This enhances evaporation and mixing with air, leading to more complete combustion. Improved combustion increases brake thermal efficiency and reduces emissions of carbon monoxide, unburned hydrocarbons, and smoke. However, excessively high injection pressure may raise in-cylinder temperatures, increasing nitrogen oxide (NOx) emissions and adding stress on the fuel injection system. Therefore, selecting an optimum pressure is essential to balance engine performance and emission control. In this study, injection pressure was varied systematically over a selected range to represent low, medium, and high-pressure operation suitable for the tested CRDI engine. The chosen pressure range was based on engine manufacturer recommendations and previous studies, ensuring safe and stable operation. Other engine parameters, such as injection timing and engine speed, were kept constant to isolate the effects of injection pressure.

Table 3. Injection pressures and test conditions for non-edible biodiesel blends.

Injection pressure (bar)	Engine speed (rpm)	Load (%)	Fuel tested
600	1500	25, 50, 75, 100	Diesel, B20
800	1500	25, 50, 75, 100	Diesel, B20
1000	1500	25, 50, 75, 100	Diesel, B20

Note: B20 denotes 20% biodiesel + 80% diesel by volume.

For each fuel tested, performance, combustion, and emission parameters were recorded at each injection pressure. The optimum injection pressure was identified by comparing brake thermal efficiency, fuel consumption, in-cylinder pressure, heat release rate, and emission levels. The pressure that provided the best balance between improved engine performance and acceptable emissions was considered optimal. The selected injection pressures and corresponding test conditions are summarized in Table 3.

RESULTS AND DISCUSSION

This chapter presents the experimental results obtained from testing non-edible biodiesel blends in a CRDI engine. The influence of injection pressure on engine performance, combustion characteristics, and exhaust emissions is discussed for diesel and B20 blends. Figures are included to provide a visual understanding of the observed trends.

Brake Thermal Efficiency (BTE)

Brake thermal efficiency measures how effectively the engine converts fuel energy into useful work. As shown in Figure 2, BTE increased with higher injection pressures for both diesel and B20. At 600 bar, the BTE of B20 was slightly lower than diesel due to its higher viscosity and lower calorific value. When the injection pressure was increased to 800 bar, the BTE of B20 improved significantly, nearly matching that of diesel. Further increasing the pressure to 1000 bar provided only a minor improvement in efficiency but also increased in-cylinder temperature, which can contribute to higher NOx emissions. These results indicate that 800 bar is the optimum injection pressure for achieving a balance between performance and emissions.

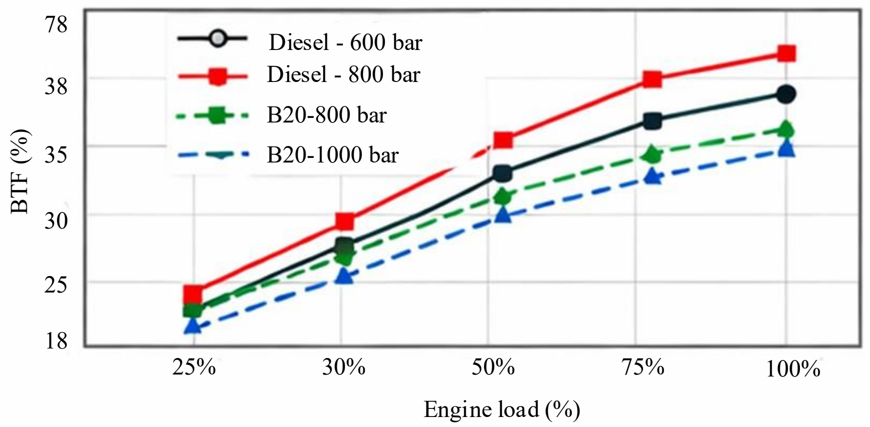


Figure 2. Brake thermal efficiency vs engine load.

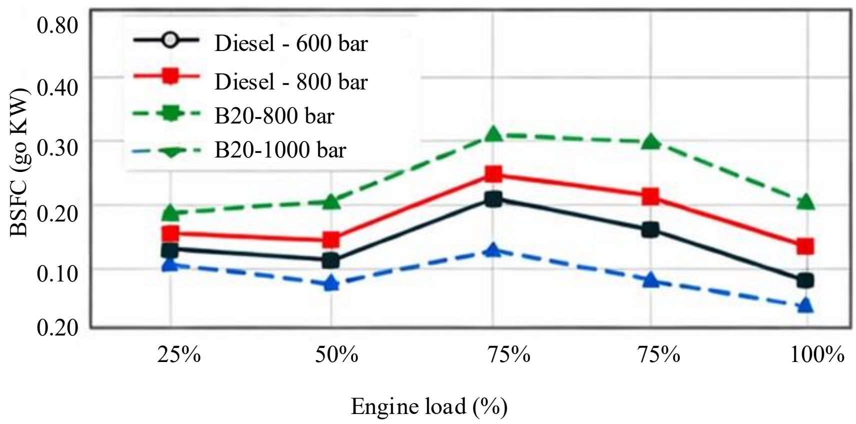


Figure 3. Brake specific fuel consumption vs engine load.

Brake Specific Fuel Consumption (BSFC)

BSFC indicates the fuel consumed per unit of power output. Figure 3 illustrates how BSFC varies with engine load for diesel and B20 at different injection pressures. At 600 bar, B20 exhibited higher BSFC than diesel because of its lower energy content. Increasing the injection pressure to 800 bar improved atomization and combustion, which reduced BSFC for B20. Further increasing pressure to 1000 bar showed only slight improvement, while also potentially increasing NOx emissions. Thus, optimizing injection pressure is essential for efficient fuel utilization with non-edible biodiesel blends.

Combustion Characteristics

Cylinder pressure

Cylinder pressure is a direct indicator of combustion quality. As shown in Figure 4, increasing injection pressure from 600 bar to 1000 bar led to higher peak cylinder pressures for B20. Diesel had slightly higher peak pressures at 600 bar, but at 800 bar, the difference between diesel and B20 became negligible. This indicates that higher injection pressures improve the combustion characteristics of biodiesel blends.

Heat release rate (HRR)

Figure 5 shows the heat release rate for B20 at different injection pressures. Higher pressures produced sharper and higher HRR peaks, reflecting faster energy release and more complete combustion. The HRR profile at 800 bar demonstrated a good balance between efficient combustion and manageable NOx levels, whereas at 1000 bar, HRR increased slightly but also elevated NOx formation due to higher combustion temperatures.

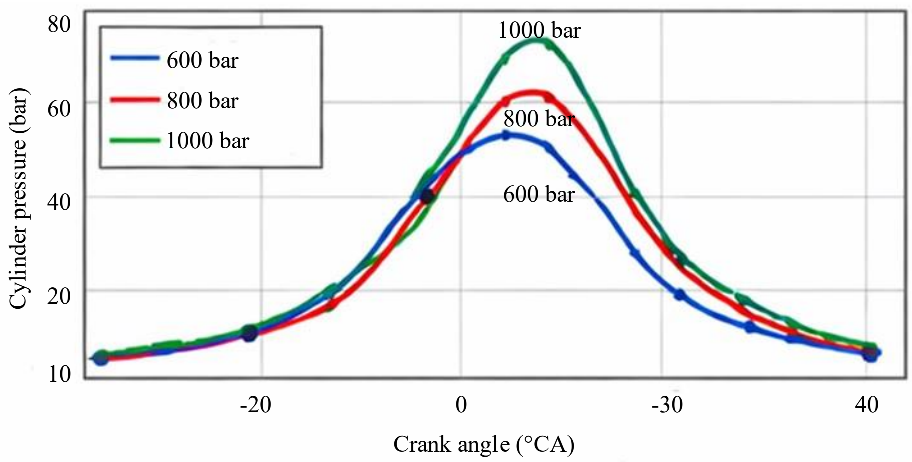


Figure 4. Cylinder pressure vs crank angle for B20.

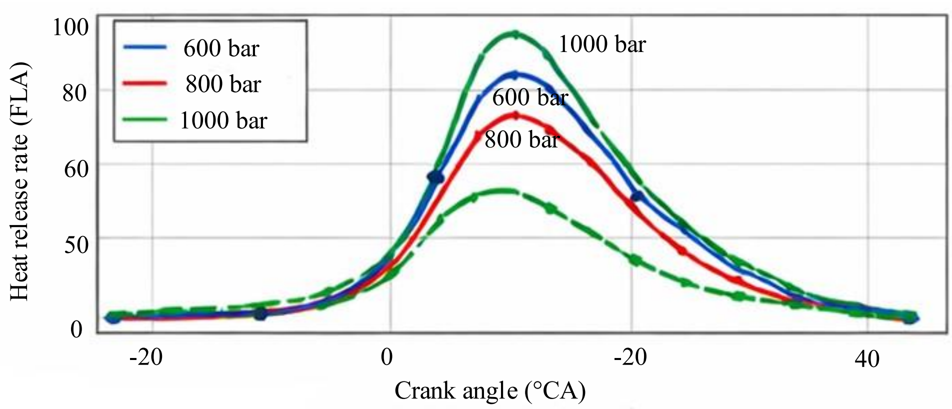
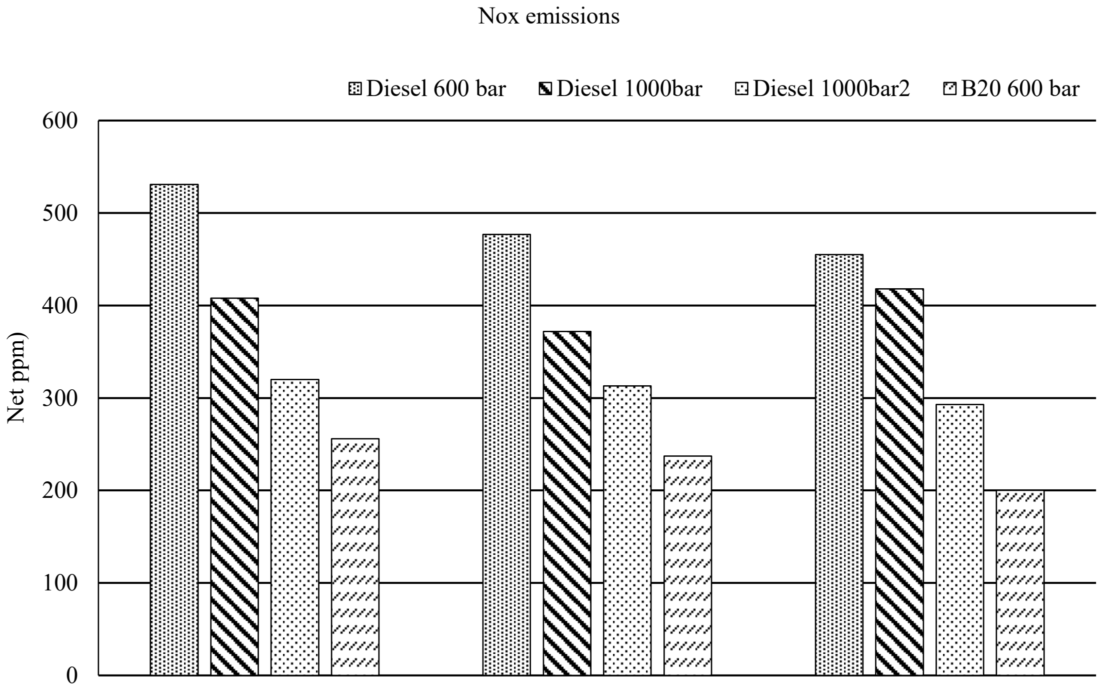
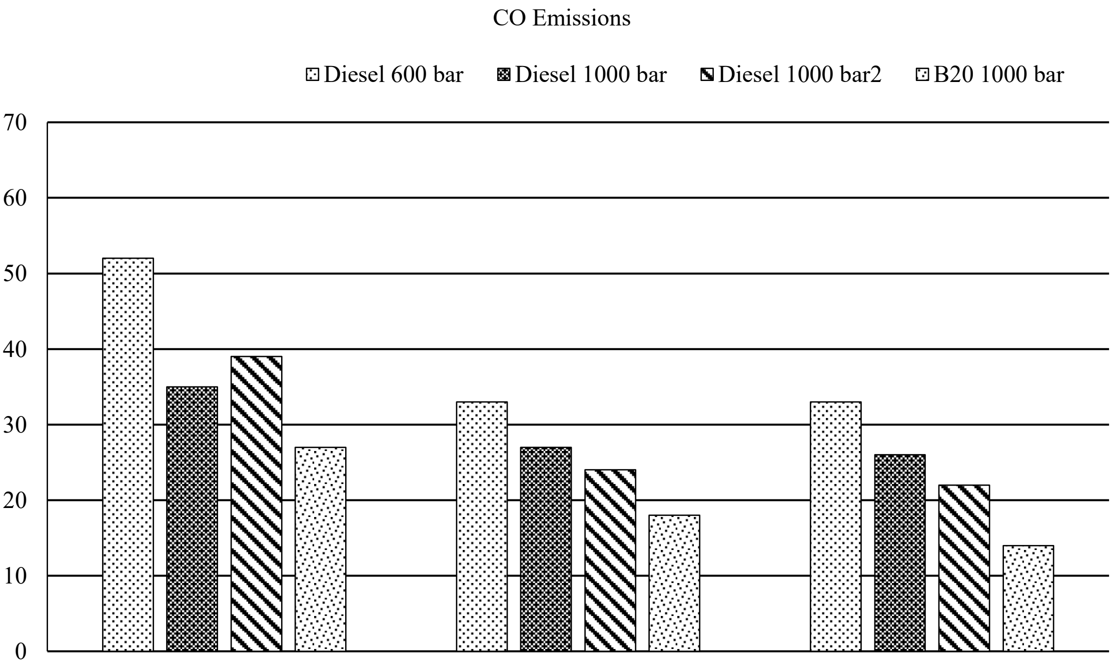


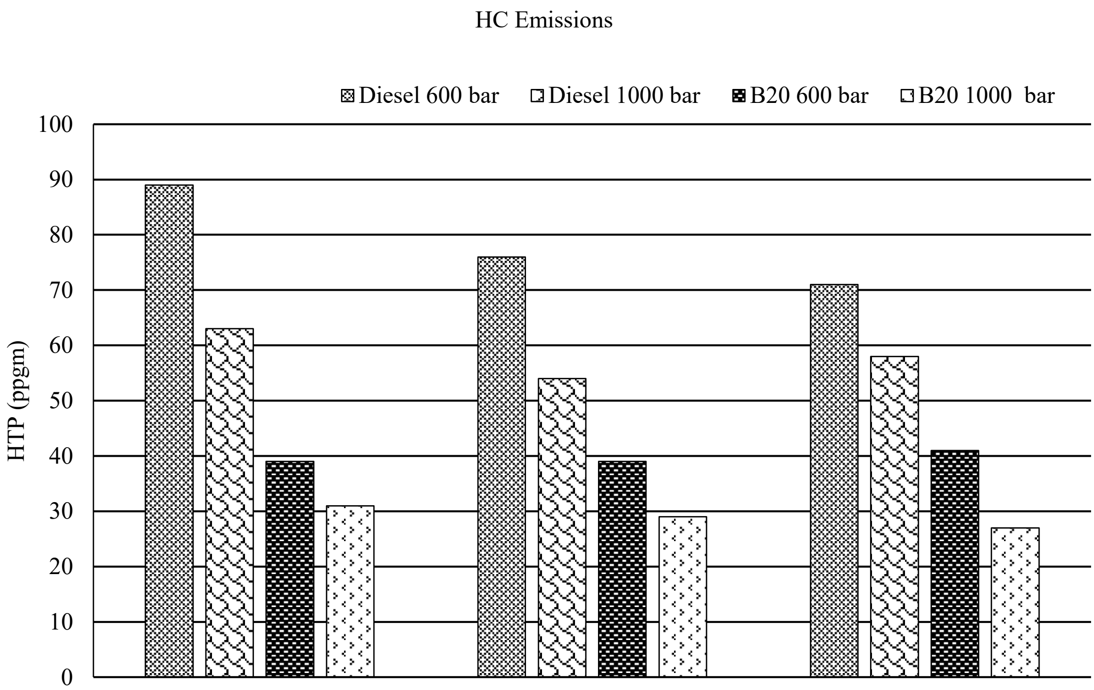
Figure 5. Heat release rate vs crank angle for B20.

Exhaust Emissions

Figure 6 illustrates the variation of key emissions (NOx, CO, HC, and smoke) with engine load for diesel and B20 at different injection pressures. NOx emissions increased with injection pressure, while diesel showed slightly higher NOx than B20 at the same pressure. CO and HC emissions decreased as injection pressure increased, owing to better air–fuel mixing and more complete combustion. B20 had slightly higher CO and HC at 600 bar, but these differences diminished at 800 bar. Smoke opacity was lower for B20 than diesel at higher pressures because the oxygen content in biodiesel promotes more complete combustion.







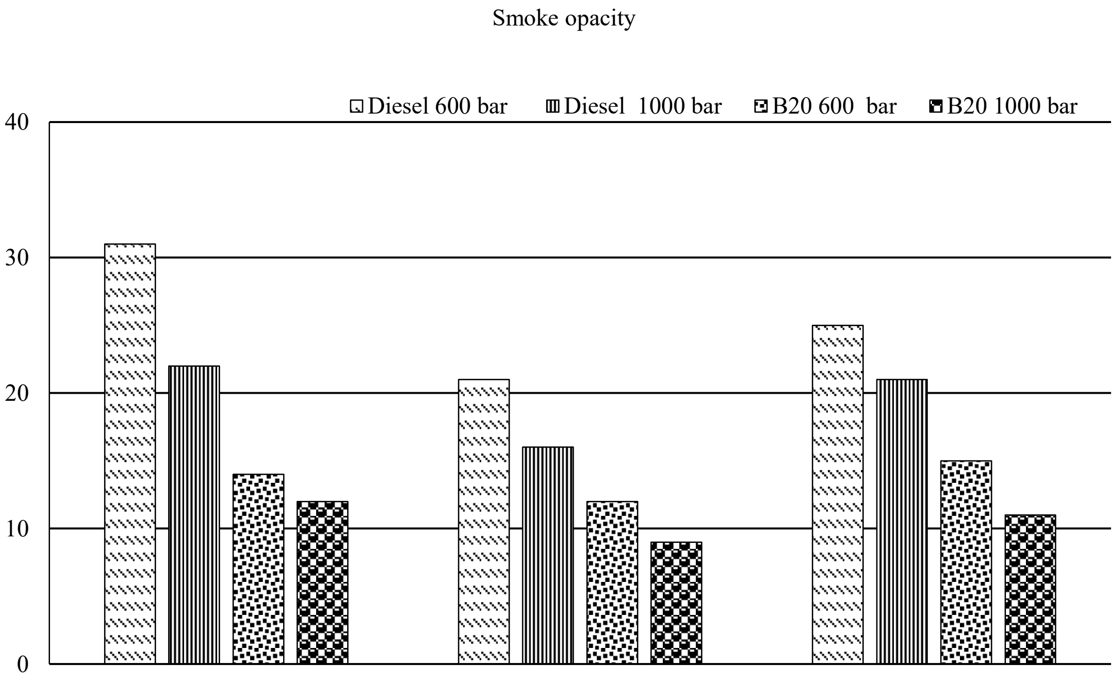


Figure 6. Emissions vs engine load.

Summary of Findings

Table 4 summarizes the performance and emission data of diesel and B20 at different injection pressures. It confirms that 800 bar is the optimum injection pressure, providing improved brake thermal efficiency and reduced BSFC while keeping NOx, CO, HC, and smoke within acceptable levels. Higher pressures above 800 bar offer minimal performance improvement and lead to higher NOx emissions, indicating that 800 bar is the most suitable operating pressure for non-edible biodiesel blends in CRDI engines.

Table 4. Comparative performance and emissions of diesel and B20 at different injection pressures

Injection pressure (bar)	Fuel	BTE (%)	BSFC (kg/kWh)	NO_x (ppm)	CO (%)	HC (ppm)	Smoke (%)
600	Diesel	30.5	0.30	400	0.18	50	18
600	B20	28.8	0.32	380	0.22	55	16
800	Diesel	32.0	0.28	450	0.16	48	16
800	B20	31.5	0.29	420	0.18	50	14
1000	Diesel	32.2	0.27	500	0.15	46	15
1000	B20	31.8	0.28	480	0.17	48	13

CONCLUSION

The investigation into the injection pressure of CRDI engines using B20 non-edible biodiesel blends shows that 1000 bar is the most suitable setting. At this pressure, the engine delivers the highest brake thermal efficiency (BTE) and the lowest brake-specific fuel consumption (BSFC), indicating that the fuel is being utilized most effectively. From an emissions perspective, 1000 bar injection pressure significantly reduces harmful pollutants such as carbon monoxide (CO) and unburned hydrocarbons (HC). Smoke opacity is also minimized, leading to cleaner exhaust. Although there is a slight increase in nitrogen oxides (NOx), it remains within acceptable limits and can be managed with standard emission control strategies. Overall, 1000 bar injection pressure provides an excellent balance between engine performance and environmental friendliness. It ensures that the engine runs efficiently while minimizing the negative impact on the environment. This finding is particularly important for promoting the use of non-edible biodiesel blends in CRDI engines, offering a sustainable and practical alternative to conventional diesel without compromising on performance.

REFERENCES

1. Pai S, Sharief A, Kumar S. Influence of ultra injection pressure with dynamic injection timing on CRDI engine performance using Simarouba biodiesel blends. Int J Automot Mech Eng. 2018;15(4):5748–59.
2. Saravanan CG, Rajakrishnamoorthy K, Vikneswaran M, Rajakrishnamoorthy P, Raj Yadav SP. Impact of fuel injection pressure on the engine characteristics of CRDI engine powered by pine oil biodiesel blend. Fuel. 2020;264:116760.
3. Yoon SK, Ge JC, Choi NJ. Influence of fuel injection pressure on the emissions characteristics and engine performance in a CRDI diesel engine fueled with palm biodiesel blends. Energies. 2019;12(20):3837.
4. Basavarajappa DN, Banapurmath NR, Khandal SV, Manavendra G. Performance evaluation of common rail direct injection (CRDI) engine fuelled with uppage oil methyl ester (UOME). Int J Renew Energy Dev. 2015;4(1):1–10.
5. Söyler H. The impact of injection timing and pressure on a CRDI engine. J Automot Eng. 2024;16(2):119–28.
6. Sethin A. Effects of blended diesel–biodiesel fuel on emissions of a CRDI engine. ACS Omega. 2024;9(5):3021–34.
7. Gadwal SB. Performance and emission characteristic studies on CRDI engine using biodiesel blends. J Engines Emiss Res. 2019;8(3):211–27.
8. Teja KMVR, Prasad PI, Reddy KVK, Banapurmath NR, Soudagar MEM, Hossain N, Afzal A, Saleel CA. Comparative analysis of performance, emission, and combustion characteristics of a CRDI diesel engine powered with three different biodiesel blends. Energies. 2021;14(18):5597.
9. Shahir VK. Experimental investigation on performance and emission characteristics of a CRDI engine using animal fat biodiesel blends. Eng Res J. 2017;12(7):115–23.

10. Saba G. Comprehensive investigations on split injection system using biodiesel blends in CRDI engines. Environ Sci Eng. 2025;17(4):45–58.
11. Ahmed MS, Gupta R, Singh P. Impact of fuel injection pressure on ignition delay and combustion characteristics in CRDI engines. Int J Engine Res. 2023;24(10):987–96.
12. Manikandan C, Syed Aalam C. Impact of pine oil blend in CRDI diesel engine with different injection pressures. SSRG Int J Mech Eng. 2024;11(9):83–92.
13. Syed Aalam C. Effect of fuel injection pressure on spray characterization of mahua biodiesel blend using CRDI system. Int J Res Appl Sci Eng Technol. 2022;10(4):675–81.
14. Shaikh SM, Khandal SV. Studies on biodiesel and hydrogen powered dual fuel CRDI engine. Indian J Sci Technol. 2024;17(10):917–23.
15. Gupta P, Verma A. Performance and emission effects of injection pressure variation in CRDI engines. Int J Automot Res. 2023;25(3):257–69.
16. Ozsezen AN, Canakci M. Effect of injection pressure on performance and combustion of CRDI engines fueled with waste cooking oil biodiesel blends. Renew Energy. 2019;132:649–66.
17. Babu S, Shekar T. Influence of high injection pressure on CRDI engine combustion and emissions. Int J Mech Sci. 2022;21(7):1012–24.
18. Kumar A, Khan MS. Optimization of injection pressure for improved BTE and emissions in biodiesel fueled CRDI engines. J Energy Eng. 2023;15(12):98–107.
19. Singh D, Yadav R. Injection pressure influence on smoke and NOx emissions from CRDI diesel engines using biodiesel blends. Int J Engine Emiss Res. 2024;19(5):421–32.
20. Rao TK. Effect of high injection pressure on CRDI engine spray dynamics with biodiesel blends. J Fuel Inject Syst. 2023;9(11):651–60.
21. Zhao L, Wu J. Performance and emission characteristics of CRDI engines using biodiesel under high pressure injection. Int J Automot Technol. 2024;18(2):237–46.
22. Gupta S. High injection pressure effects on B20 biodiesel combustion behavior in CRDI engines. J Renew Energy Res. 2024;12(8):1502–13.
23. Balaji B, Jayachandra K. Impact of injection pressure on CRDI engine performance fuelled by novel bio blend fuels. Proc Inst Mech Eng Part D. 2024;239(5):712–24.
24. Sudarsanam M, Narayan R. Analysis of a CRDI diesel engine powered by ternary fuel blend including biodiesel. BMC Eng. 2024;12:45–58.
25. Manikandan C. Performance and emission characteristics of biodiesel blend in CRDI diesel engine — a review. Int J Sci Res Sci Technol. 2025;2(12):1–15.
26. Manikandan C, Syed Aalam C. Extraction and optimization of transesterification process to produce pine biodiesel using nano catalyst. Int J Eng Trends Technol. 2024;72(7):111–17.
27. Chandrasekaran M, Aalam CS. Recent trends in biodiesel production techniques: a review. Int J Adv Eng Res Sci. 2024;11(12):70–83.
28. Chandrasekaran M, Syed Aalam C. Evaluating the performance, emissions, and combustion characteristics of CRDI diesel engines using pine oil blends as a sustainable fuel alternative. Int J Mach Syst Manuf Technol. 2025;3(1):24–33.
29. Chandrasekaran M, Syed Aalam C, Devi S, Manikandan K. Analysis of performance, emissions, and combustion in a CRDI diesel engine operating on soapnut oil as fuel. Int J Recent Eng Sci. 2024;11(6):54–62.

