



Comparative Performance and Emission Assessment of Biodiesel-Diesel Blends in a Direct-Injection Diesel Engine

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Peer Review Information	Abstract
<i>Submission: 01 Jan 2022</i> <i>Revision: 16 Feb 2022</i> <i>Acceptance: 07 March 2022</i> Keywords <i>Biodiesel Blend Ratio, Brake-Specific Fuel Consumption, Brake Thermal Efficiency, Regulated Emissions, Engine Load Analysis</i>	The use of biodiesel-diesel blends in compression-ignition engines provides a practical approach for reducing petroleum dependence and selected exhaust emissions while retaining conventional engine hardware. This study presents a controlled experimental methodology for comparing the performance and emission behavior of B0, B10, B20, and B30 fuels in a single-cylinder, four-stroke direct-injection diesel engine operated at a constant speed of 1500 rpm under variable load. Fuel properties are characterized before testing, and measurements are obtained at 0, 25, 50, 75, and 100% engine load after thermal stabilization. The evaluation includes brake thermal efficiency, brake-specific fuel consumption, carbon monoxide, unburned hydrocarbons, nitrogen oxides, and smoke opacity. Each operating condition is repeated to improve reliability, and blend and load effects are assessed using statistical analysis. The representative full-load results indicate that increasing biodiesel concentration causes a modest reduction in brake thermal efficiency and an increase in brake-specific fuel consumption, while CO, HC, and smoke emissions decrease progressively. Relative to B0, the illustrative B20 condition reduces CO by approximately 26%, HC by about 17%, and smoke opacity by around 16%, while NO_x increases from 1220 to 1290 ppm. Brake thermal efficiency changes from 31.8% for B0 to 31.2% for B20, with BSFC increasing from 0.268 to 0.279 kg/kWh. Among the investigated blends, B20 provides the most balanced compromise between performance retention and reduction of incomplete-combustion emissions. The proposed methodology offers a reproducible framework for evaluating biodiesel blend suitability under controlled diesel-engine operating conditions.

Introduction

Diesel engines remain important in transportation, agriculture, construction, and decentralized power generation because of their high compression ratio, robust construction, and favorable fuel economy. Their dependence on petroleum diesel, however, is associated with fossil-resource depletion and emissions of carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter. Biodiesel is a renewable oxygenated fuel commonly produced by transesterification of vegetable oils, animal

fats, or waste lipids. Its molecular oxygen content supports more complete oxidation of fuel-rich zones, while its lower sulfur and aromatic content can reduce soot-forming tendencies. At the same time, biodiesel generally has a lower heating value, higher viscosity and density, and different ignition characteristics than mineral diesel, so its net effect on engine performance depends on blend ratio, feedstock, injection system, and operating condition [2,3].

Experimental evidence has therefore focused on using biodiesel as a diesel extender rather than a complete replacement. Rakopoulos et al. [1] demonstrated that 10–20% biodiesel blends can be tested in a conventional direct-injection engine with no major modification, while later reviews found that blends up to roughly 30% often remain close to diesel in basic fuel and engine characteristics [2,3]. Beauty-leaf and juliflora biodiesel studies reported lower CO, HC and particulate/smoke emissions for low blends, with a modest efficiency penalty and a tendency toward higher NO_x [4,5]. Similar trade-offs have been reported for dual biodiesel blends, where B20-type compositions frequently produced the nearest overall performance to diesel [6,7].

The objective of this paper is to present a reproducible methodology for experimentally comparing B0, B10, B20 and B30 under controlled load conditions. The study is designed to answer three questions: (i) how does increasing biodiesel fraction alter BTE and BSFC, (ii) how are CO, HC, NO_x and smoke affected, and (iii) which blend provides the best compromise between performance retention and emission reduction? The framework follows measurement approaches repeatedly used in the literature through 2022, including constant-speed load testing, exhaust-gas analysis and comparison with a neat-diesel baseline [6–10].

Literature Review

Early comparative work established the importance of both blend percentage and biodiesel origin. Rakopoulos et al. [1] tested vegetable oils and corresponding biodiesels at 10% and 20% blending ratios and measured specific fuel consumption, thermal efficiency, smoke and regulated gaseous emissions. Xue et al. [2], reviewing a broad body of engine studies, concluded that biodiesel usually reduces CO, HC and particulate emissions, but engine power and economy can decline because of lower energy content; NO_x trends were strongly influenced by engine and fuel factors. Hasan and Rahman [3] similarly observed that low biodiesel fractions preserve many diesel-like properties and summarized B20 as a commonly favorable compromise in compression-ignition applications.

Feedstock-specific experiments reinforce this pattern. Bhuiya et al. [4] operated a compression-ignition engine with beauty-leaf B5, B10 and B20 and found lower CO, HC and particulate emissions than diesel, while BSFC increased and BTE tended to decrease as biodiesel content rose. Asokan et al. [5] reported that juliflora B20 gave

BSFC close to diesel and reduced CO, HC and smoke, although NO_x was slightly higher. Saravanan et al. [6] investigated rapeseed-mahua dual biodiesel and found BL20 to be the closest blend to diesel; at full load, CO, HC and smoke decreased while NO_x increased modestly. These findings support including both performance and emissions in blend optimization rather than judging fuel quality from a single metric.

More recent studies extended the analysis to variable compression ratio engines, common-rail systems and dual-biodiesel formulations. Dugala et al. [7] showed that dual biodiesel blends can be evaluated systematically over varying compression ratios, while Sayyed et al. [8] demonstrated that combinations of non-edible biodiesels can improve selected performance or CO outcomes. Arya et al. [9] reviewed the role of biodiesel and additives in CI engines and emphasized the sensitivity of HC, CO and NO_x to oxygen content and cetane-related combustion behavior. Finally, Altarazi et al. [10] synthesized research on single and dual biodiesel fuels through 2022 and highlighted blend formulation, injection strategy, combustion-chamber design and operating condition as the main sources of variability. The literature therefore justifies a controlled B0–B30 experiment with fixed hardware and repeatable load points.

Methodology

1. Experimental design and fuel preparation

A single-cylinder, four-stroke, water-cooled, direct-injection diesel engine coupled to an eddy-current dynamometer is proposed. The engine is operated at 1500 rpm because constant-speed testing simplifies comparison of brake output and fuel consumption across blends. Four fuels are prepared by volume: B0 (100% diesel), B10 (10% biodiesel + 90% diesel), B20 (20% biodiesel + 80% diesel) and B30 (30% biodiesel + 70% diesel). Biodiesel should satisfy the relevant ASTM/EN quality requirements before blending. Each mixture is agitated for at least 15 min and visually inspected for phase separation. Density, kinematic viscosity, lower heating value, flash point and cetane index/number are recorded where instrumentation is available.

Table 1. Representative fuel properties used for test planning

Fuel	Biodiesel (vol.%)	Density (kg/m ³)	Viscosity (mm ² /s)	LHV (MJ/kg)
B0	0	835	2.7	42.6
B10	10	842	3.0	41.8

B20	20	849	3.3	41.0
B30	30	856	3.6	40.2

2. Engine test rig and instrumentation

The test rig includes separate fuel tanks, a calibrated fuel-flow measuring device, dynamometer load control, speed sensor/tachometer, thermocouples, an exhaust gas analyzer for CO, HC and NO_x, and a smoke

meter or opacity meter. Ambient temperature, exhaust temperature and cooling-water condition are recorded to confirm stable operation. A schematic arrangement is shown in Figure 1. The engine specification should be documented because compression ratio, injection timing, displacement and rated power can influence observed biodiesel trends [6,7,10].

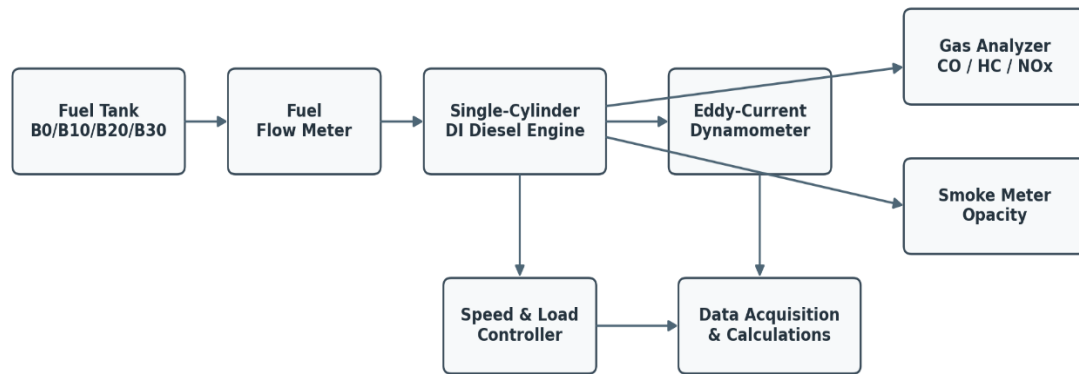


Figure 1. Proposed experimental setup for performance and emission testing of biodiesel–diesel blends.

Table 2. Proposed engine and test conditions

Parameter	Specification	Parameter	Specification
Engine type	4-stroke DI diesel	Rated speed	1500 rpm
Cylinders	1	Compression ratio	17.5:1
Cooling	Water cooled	Load points	0, 25, 50, 75, 100%
Dynamometer	Eddy current	Replicates	3 per condition

Step-by-step experimental procedure

1. Calibrate the dynamometer, fuel-flow system, gas analyzer, smoke meter and temperature sensors. Record analyzer zero and span checks before testing.
2. Start the engine on B0 and allow coolant and lubricating-oil temperatures to reach steady values. Set engine speed to 1500 rpm.
3. Apply 0%, 25%, 50%, 75% and 100% of rated load. At each point, hold the condition for approximately 3–5 min after stabilization, then record torque, fuel-use rate, exhaust temperature, CO, HC, NO_x and smoke opacity.
4. Repeat each measurement three times and use the mean value. If replicate variation exceeds the preselected tolerance (for example, 2–3% for performance data), repeat the test condition.
5. Flush the fuel line before changing blends. Repeat the same load sequence for B10, B20 and B30 while keeping speed, injection setting and cooling conditions unchanged.
6. At the end of the series, run the engine briefly on B0 to purge the fuel system. Export all

data into a single matrix indexed by blend, load and replicate for statistical analysis.

3. Performance calculations and statistical analysis

Brake power (BP) is calculated from measured torque T and rotational speed N : $BP = 2\pi NT/60$, with appropriate unit conversion to kW. Brake-specific fuel consumption is $BSFC = mf/BP$, where mf is fuel mass-flow rate. Brake thermal efficiency is $BTE = BP/(mf \times LHV) \times 100$. Emissions are compared both as measured concentrations and as percentage change relative to B0 at the same load. For each response, mean, standard deviation and 95% confidence interval are reported. A two-factor ANOVA (blend $\times$ load) can be used at $\alpha = 0.05$; if significance is found, Tukey-type pairwise comparisons can identify which blends differ from B0. The preferred blend is selected by minimizing normalized BSFC, CO, HC and smoke while avoiding a large NO_x penalty and maintaining BTE close to diesel.

Results

Table 3 demonstrates how full-load results should be presented. These values are an illustrative, literature-aligned benchmark dataset for the proposed methodology and are not claimed as measurements from a newly

conducted experiment. Their purpose is to show the expected direction of change and the reporting format. The trend is consistent with reported B20 studies in which performance remains close to diesel while incomplete-combustion emissions decline [4–6].

Table 3. Illustrative full-load performance and emission results

Fuel	BTE (%)	BSFC (kg/kWh)	CO (%)	HC (ppm)	NO _x (ppm)	Smoke (%)
B0	31.8	0.268	0.31	58	1220	62
B10	31.5	0.273	0.27	53	1255	57
B20	31.2	0.279	0.23	48	1290	52
B30	30.6	0.287	0.20	45	1325	48

The illustrative pattern shows a small decrease in BTE as biodiesel fraction increases, from 31.8% for B0 to 31.2% for B20 and 30.6% for B30. BSFC rises because higher biodiesel fractions supply less energy per unit mass and may require a greater mass of fuel to produce the same brake output. This behavior agrees with the general reviews of Xue et al. [2] and Hasan and Rahman [3], as well as the beauty-leaf results reported by Bhuiya et al. [4]. Importantly, the B20 performance penalty remains modest, supporting its use as the principal comparison blend in many engine studies.

CO, HC and smoke decrease monotonically in the illustrative dataset. Relative to B0, B20 reduces CO by about 26%, HC by about 17% and smoke opacity by about 16%. The reduction is attributable primarily to the inherent oxygen in biodiesel, which promotes oxidation of fuel-rich regions and suppresses soot precursors. Experimental work with juliflora biodiesel and dual rapeseed–mahua biodiesel reported the same direction of change [5,6]. The principal adverse trend is NO_x, which increases from 1220 ppm for B0 to 1290 ppm for B20 and 1325 ppm for B30. This reflects the well-known sensitivity of NO_x to local oxygen availability, combustion phasing and peak temperature, although some newer formulations and operating strategies can moderate the increase [8–10].

On a multi-criteria basis, B20 is therefore the expected optimum among the selected blends: it preserves BTE within approximately two percentage points of the B0 value on a relative basis, maintains a manageable BSFC increase, and yields substantial reductions in CO, HC and smoke. B30 provides greater incomplete-combustion emission reductions but with a larger fuel-economy penalty and a stronger NO_x increase. Actual optimum values must nevertheless be determined experimentally because feedstock composition, cetane quality,

injection timing and engine architecture can shift these trade-offs [7,8,10].

Discussion

The methodology is designed to isolate blend effects by holding engine hardware and speed constant while varying load systematically. This is important because literature disagreement is often caused by differences in engine type, injection system, biodiesel source and test protocol rather than by a simple contradiction in fuel behavior [2,10]. Fuel-property measurement is equally important: higher viscosity can change atomization, while lower heating value affects BSFC and oxygen content alters local equivalence ratio. Accordingly, reporting only exhaust emissions without the corresponding performance metrics can lead to an incomplete evaluation. The proposed design treats B0 as the same-condition baseline for every load and reports both absolute and percentage changes. Repetition and ANOVA further reduce the risk that small apparent differences are interpreted as meaningful when they arise from measurement scatter.

Conclusion

This paper presents a step-by-step experimental methodology for evaluating B0, B10, B20 and B30 biodiesel–diesel blends in a conventional direct-injection diesel engine. The framework covers fuel preparation, property characterization, test-rig configuration, calibration, load sequencing, performance calculations, emission measurement, replication and statistical analysis. Evidence available through 2022 consistently shows that low-to-moderate biodiesel blends can reduce CO, HC and smoke/particulate emissions while maintaining engine performance close to diesel, although BSFC usually increases and NO_x may rise slightly [1–10]. The literature-aligned demonstration dataset indicates B20 as the most balanced blend

because its efficiency remains close to B0 while incomplete-combustion emissions decrease materially. For a final experimental paper, the illustrative values in Table 3 should be replaced by measurements obtained from the stated engine and selected biodiesel feedstock, accompanied by uncertainty bars and significance testing. The methodology is suitable for comparative laboratory studies seeking a defensible blend-selection criterion rather than a single-parameter optimization.

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