Ijfans International Journal of Food and Nutritional Sciences
ISSN PRINT 2319 1775 Online 2320 7876
Research Paper © 2012 IJFANS. All Rights Reserved, Journal UGC CARE Listed (Group-I) Volume 10, Issue 01 Jan, 2021

Experimental Evaluation of Neem-Derived Biofuel Blends for Cleaner Compression Ignition Engine Operation

Ankur Bhatia[1], D. V. Patel[2], Dr. Prashant S. Kadu[3]
[12]Department of Mechanical Engineering
[12]Sri Satya Sai University of Technology & Medical Sciences, Sehore, Madhya Pradesh, India
[3]Principal.Abha-Gaikwad Patil College of Engineering,Nagpur
[1]ankurbhatia78k2@gmail.com
[3]pskadu@gmail.com

Abstract

Growing pressure to curb tailpipe emissions and reduce dependence on imported crude has renewed interest in non-edible, tropical biodiesel feedstocks as drop-in diesel substitutes. This paper presents an experimental performance, combustion and emission assessment of a single-cylinder, four-stroke, water-cooled variable compression ratio (VCR) direct-injection diesel engine operated on Neem Methyl Ester (NME), its diesel blends (B10, B20, B30, B40) and diesel-NME-methanol ternary blends (B1, B2), benchmarked against mineral diesel. Tests spanned compression ratios of 14, 15, 16 and 17.5 at a constant speed of 1500 rpm, from no-load to full-load, with in-cylinder pressure, brake thermal efficiency, brake specific fuel consumption, exhaust emissions (CO, CO2, HC, NOx, smoke) and structure-borne vibration all recorded on a common test bed. NME reduced peak net heat release rate by roughly 20.7% and cut full-load HC emissions by 60-100% relative to diesel, at the cost of a 0.6-percentage-point BTE penalty and higher smoke opacity. The associated fall in rate-of-pressure-rise also manifested as a measurable reduction in combustion-induced vibration, confirming vibration as a useful secondary indicator of the cleaner, more gradual combustion achieved with NME. Blends B10 and B1 offered the most balanced performance-emission trade-off among all fuels tested, making them attractive near-term candidates for unmodified diesel engines.

Keywords: Neem Methyl Ester; biodiesel blends; brake thermal efficiency; exhaust emissions; combustion analysis; variable compression ratio diesel engine.

1. Introduction

The compression-ignition diesel engine continues to power the bulk of global freight, agricultural machinery and off-grid electricity generation on account of its high thermal efficiency and mechanical robustness. Yet its dependence on a finite fossil resource, together with regulatory limits on particulate matter, NOx and CO2, has made biodiesel one of the most actively pursued near-term replacement fuels. Feedstocks such as neem, jatropha and waste cooking oil allow biodiesel production without competing with the edible-oil supply chain, and transesterified biodiesel can typically be used in existing diesel engines with little or no hardware change.

Most published work on biodiesel substitution focuses on brake thermal efficiency, brake specific fuel consumption and regulated emissions, generally reporting a trade-off between cleaner combustion and a modest efficiency or fuel-economy penalty. A smaller stream of work additionally tracks engine vibration, since the rate of in-cylinder pressure rise that governs emissions and knock also excites structure-borne vibration that can be measured non-intrusively. Few studies, however, integrate performance, emission, combustion and vibration measurements on a single test bed across multiple compression ratios for a non-edible feedstock such as neem oil — the scope adopted in this work.

The remainder of the paper is organised as follows. Section 2 reviews relevant prior studies. Section 3 defines the research gap and objectives. Section 4 describes fuel preparation and the experimental test rig. Section 5 presents performance, emission, combustion and vibration results together. Section 6 concludes and outlines future scope.

2. Literature Review

A considerable volume of published research addresses biodiesel-fuelled compression-ignition engines from the standpoint of combustion quality, power output and regulated emissions, with a smaller but growing body of work also examining structure-borne vibration. Ten representative studies (Alptekin 2017; Nour et al. 2017; Babji and Rao 2017; Haozhong and Teng 2016; Sarangan et al. 2016; Karagoz 2016; How and Masjuki 2014; Kondaveeti and Rao 2013; Rakopoulos et al. 2012; Taghizadeh-Alisaraei et al. 2012) were screened for thematic coverage across six areas: performance, emissions, combustion analysis, vibration measurement, multi-compression-ratio testing, and use of oxygenated additives. Figure 1 plots this coverage as a radar chart, scored on a 0-5 scale by the number of studies addressing each theme.

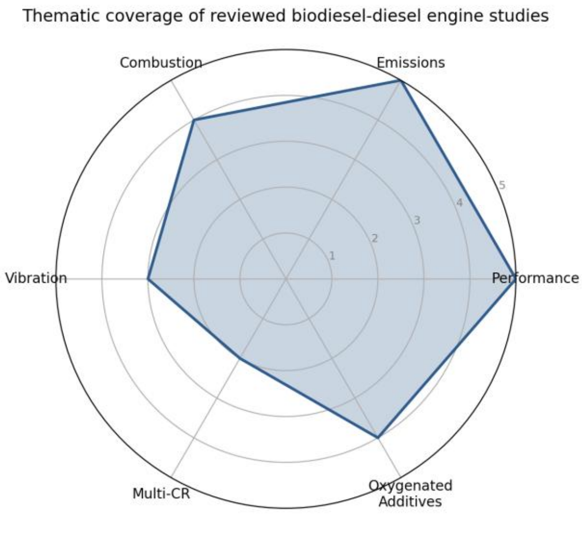

Figure 1. Radar chart of thematic coverage across the reviewed biodiesel-diesel engine literature.

Performance and emission characterisation dominate the reviewed literature (scoring 5/5), combustion analysis and oxygenated-additive studies are moderately well represented (4/5), while multi-compression-ratio testing (2/5) and, to a lesser extent, vibration measurement (3/5) remain comparatively underexploited. This imbalance is precisely the gap the present study targets: NME and its blends are examined jointly for performance, emissions, combustion and vibration across four compression ratios on a single test bed.

3. Research Gap and Objectives

Although fault-diagnostic vibration monitoring (misalignment, bearing wear, looseness) is a mature field, comparatively few studies combine compression-ratio and load sweeps with full performance, emission and combustion characterisation for a single non-edible biodiesel feedstock such as neem oil. This work addresses that gap using NME and its blends (B10-B40, B1, B2), benchmarked throughout against standard diesel.

The specific objectives of this study are to:

- Quantify brake thermal efficiency and fuel consumption for a diesel engine running on oxygenated (NME) fuel relative to diesel.
- Assess exhaust emission behaviour (CO, CO2, HC, NOx, smoke) with neem-oil-derived biodiesel as a fuel substitute.
- Characterise in-cylinder combustion parameters at compression ratios up to 17.5, benchmarked against diesel.
- Map performance and emission trends from no-load to full-load across the tested compression ratios.
- Use vibration measurement along three orthogonal directions to corroborate the combustion trends observed for NME and diesel.

4. Fuel Preparation and Experimental Programme

4.1 Fuel Preparation

Neem Methyl Ester was synthesised from crude neem seed oil via a three-step transesterification route. Acid treatment first reduced the free fatty acid content to roughly 1% using methanol and H_2SO_4 at 50-60°C. Base treatment then used a sodium methoxide solution (methanol plus NaOH) at 50-60°C for 1.5 h, followed by a 24 h settling period to separate glycerine. Finally, a phosphoric-acid water wash removed residual glycerine and soap, followed by heating to 100°C to drive off moisture. Diesel-NME binary blends B10, B20, B30 and B40 (10-40% NME by volume) and ternary blends B1 (50% diesel, 45% NME, 5% methanol) and B2 (50% diesel, 40% NME, 10% methanol) were then prepared. Resulting fuel properties, measured to ASTM standards, are listed in Tables 2 and 3.

Table 2. Measured fuel properties: diesel, NME and methanol.

Property	Method	Diesel	NME	Methanol
Calorific value (kJ/kg)	ASTM D 240	42500	38500	19674
Kinematic viscosity @ 40°C (cSt)	ASTM D 445	2.4	4.4	0.59
Density (kg/m³)	ASTM D 4052	835.6	875.8	790
Flash point (°C)	ASTM D 93	56	183	11

Table 3. Measured properties of blended test fuels B10-B40, B1 and B2.

Property	**B10**	**B20**	**B30**	**B40**	**B1**	**B2**
Calorific value (kJ/kg)	42100	41700	41300	40900	39725	38950
Kinematic viscosity @ 40°C (cSt)	2.75	2.96	3.10	3.36	3.21	3.02
Density (kg/m³)	841	846	851	856	850	847

4.2 Test Rig and Instrumentation

The test programme used a single-cylinder, four-stroke, water-cooled variable compression ratio (VCR) direct-injection diesel engine coupled to an eddy-current dynamometer. The engine ran at a fixed speed of 1500 rpm across compression ratios of 14, 15, 16 and 17.5, spanning no-load (0 kW) to full-load (3.5 kW). A piezoelectric pressure transducer (1 mV/PSI, 5000 PSI range) fitted to the cylinder head, synchronised to a TDC crank-angle encoder, provided in-cylinder pressure data for 100 consecutive cycles via a USB-6210 acquisition module, from which heat-release rate was computed using the first law of thermodynamics. A PCB triaxial accelerometer bonded to the cylinder head, sampled at 51.2 kHz for 12.5 consecutive cycles through an NI-9234 module, supplied the vibration data. Exhaust composition (CO, HC, CO_2, NOx, O_2) was measured with an AVL DiGas 444 five-gas analyser, and smoke opacity with an AVL 437C smoke meter, reported in Hartridge Smoke Units.

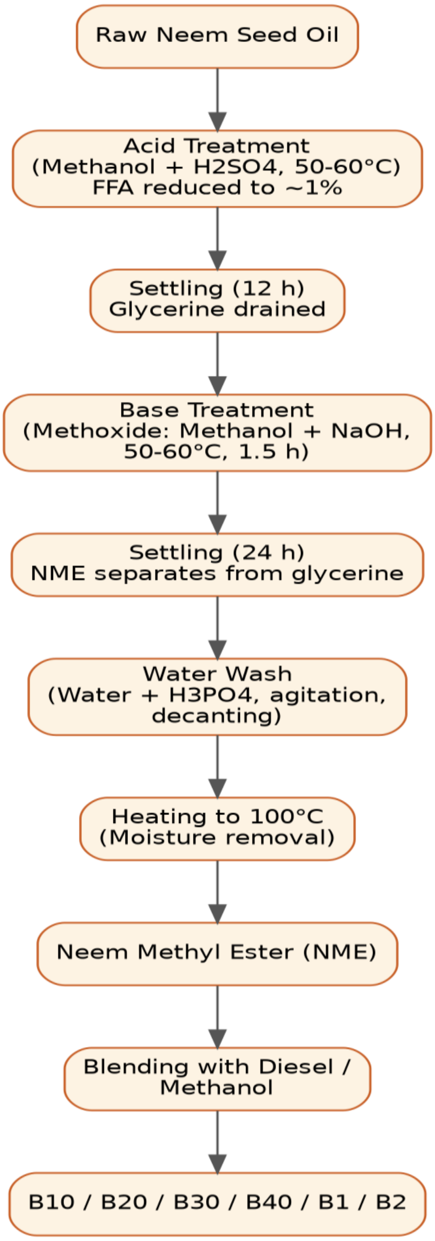

Figure 2. Neem Methyl Ester (NME) transesterification and blend-preparation process flow.

5. Results and Discussion

5.1 In-Cylinder Combustion Characteristics

Peak cylinder pressure increased with compression ratio for both fuels, reaching a maximum at CR 17.5. The percentage rise in peak pressure from no-load to full-load was largest at CR 14 (71.5% for diesel, 72.3% for NME) and smallest at CR 17 (49.8% for NME, 44.6% for diesel), showing a diminishing marginal sensitivity to load as compression ratio increases. At CR 17, peak net heat release rate (NHRR) reached 44.4 J/deg for NME against 35.2 J/deg for diesel — NME's peak NHRR is about 20.7% lower than diesel's across all loads and compression ratios, consistent with its lower calorific value and higher viscosity moderating premixed combustion. Rate of pressure rise (RPR) followed the same pattern: at full load and CR 17, peak RPR was 4.46 J/deg for NME versus 3.6 J/deg for diesel, a 23.8% difference.

5.2 Brake Thermal Efficiency and Fuel Consumption

Brake thermal efficiency (BTE) rose with load for every fuel at every compression ratio tested, peaking at CR 16 with 31.17% for diesel and 30.57% for NME — a modest 0.6-percentage-point gap traceable to NME's slightly lower energy content. The fuel-economy cost of this efficiency gap is captured in Figure 2, which plots the BSFC penalty of NME over diesel at 25% and 100% load across the four compression ratios; the penalty is largest at CR 14 (up to 32.3% at 25% load) and narrows to 7-11% by CR 16-17 as combustion becomes more complete. Among the blends, B10 recorded the lowest BSFC at every load point, while B40 marginally exceeded diesel's BTE (by 3.8% and 1.2% at 75% and 100% load) due to more advanced combustion phasing at higher biodiesel fractions.

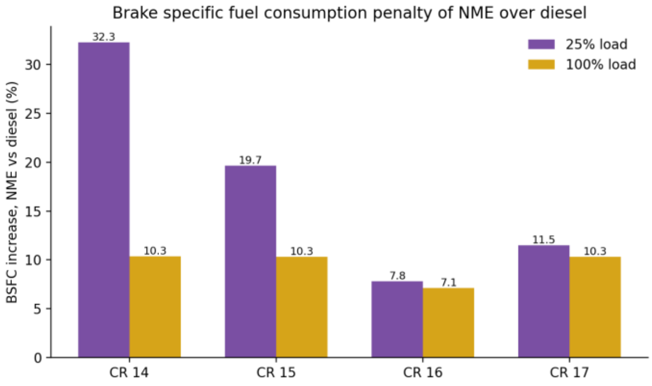

Figure 3. BSFC penalty of NME over diesel at 25% and 100% load across compression ratios.

5.3 Exhaust Emission Characteristics

CO and HC emissions fell with increasing load for both diesel and NME at every compression ratio, reflecting more complete combustion at higher in-cylinder temperature. At full load, NME's HC emissions were 60% lower than diesel's at CR 14, and 87.5-100% lower at CR 15-17 — the single largest improvement recorded in this study. Smoke opacity told the opposite story for neat NME, but among the blends B10 reversed this trend: Figure 4 shows its smoke density running 34.9-74.3% below diesel across the full load range, with the largest gain at no-load and full-load conditions.

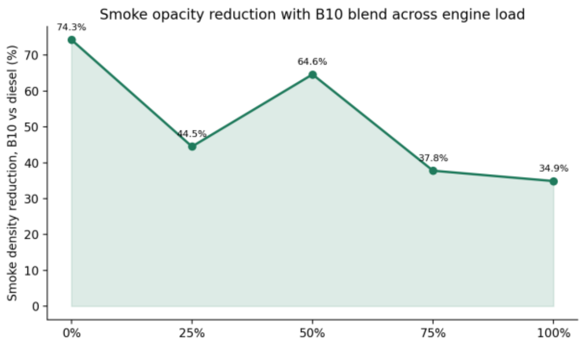

Figure 4. Smoke opacity reduction achieved with the B10 blend relative to diesel across engine load.

CO_2 emission increased initially with load before falling at higher loads for both fuels, and NOx was lower for NME than diesel at the lower compression ratios. Smoke density, however, was consistently higher for NME than diesel at every compression ratio and rose with load, a trade-off linked to NME's higher viscosity and correspondingly coarser spray atomisation. Among the blends, B10 gave the lowest smoke density (34.9-74.3% below diesel across the load range) and the lowest CO emission (66.7% below diesel at 25% load); B20 and B10 gave the lowest NOx of all fuels tested, while B40 produced comparatively higher CO_2 than the other blends.

5.4 Combustion-Induced Vibration as a Diagnostic Indicator

Because the milder heat-release and pressure-rise rates of NME (Section 5.1) directly influence structure-borne excitation, vibration was also recorded along three mutually perpendicular axes as a low-cost, non-intrusive check on the combustion trends inferred from pressure data. Time-domain signals for both fuels showed a dominant peak near 25 Hz at all compression ratios, with larger low-frequency amplitude in the lateral and longitudinal directions than the vertical direction, consistent with unbalanced reciprocating and rotating forces. In the combustion-dominated high-frequency band (2000-3000 Hz), NME produced lower vertical-direction vibration than diesel at every compression ratio and load tested. Figure 5 shows the percentage reduction in vertical vibration when switching from diesel to NME.

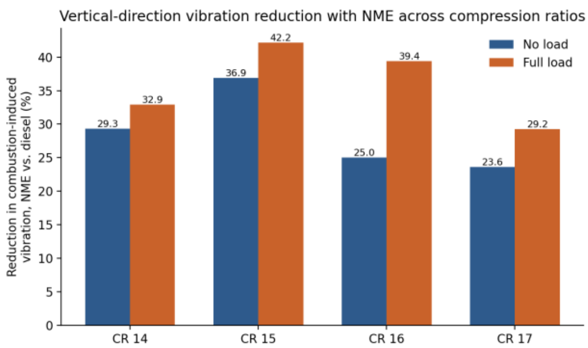

Figure 5. Reduction in vertical-direction combustion-induced vibration (NME vs. diesel) across compression ratios.

The largest full-load reduction (42.2%) occurred at CR 15 and the smallest (29.2%) at CR 17, mirroring the RPR trend identified in Section 5.1 and confirming vibration as a reliable secondary indicator of the cleaner, more gradual combustion achieved with NME. Among the blends, B10 gave the largest full-load vibration reduction relative to diesel (38.5% and 35.4% at the first and second dominant peak frequencies), while B20 performed best at no-load.

5.5 Discussion

The combined performance, emission, combustion and vibration data point to a coherent physical picture: NME's lower calorific value and higher viscosity slow and moderate the premixed combustion phase, which simultaneously lowers HC, CO and (at low CR) NOx emissions, reduces structure-borne vibration, and imposes a modest BTE/BSFC penalty together with higher smoke opacity from coarser atomisation. B10 and B1 emerge as the most balanced options across all four measurement categories — competitive efficiency, the lowest fuel-consumption penalty among the NME blends, and substantial reductions in smoke, CO and vibration — making them the strongest near-term candidates for use in existing, unmodified diesel engines.

6. Conclusion

- NME's peak NHRR and RPR are approximately 20.7% and 23.8% lower than diesel's at CR 17, indicating a milder, more gradual premixed combustion phase.
- BTE is marginally lower for NME than diesel (30.57% vs. 31.17% at CR 16), while BSFC is 7-32% higher for NME depending on operating condition.
- HC emissions for NME are dramatically lower than diesel at full load (60-100% reduction across CR 14-17); CO and NOx are also generally lower, but smoke density is consistently higher for NME.
- Vibration measurements corroborate the combustion data: NME reduces full-load vertical-direction vibration by 29.2-42.2% relative to diesel across the tested compression ratios.
- Among the blends studied, B10 and B1 provide the best overall balance of efficiency, low emissions and low vibration, and are recommended as promising near-term diesel substitutes.

These findings support the use of NME and its low-percentage blends (B10, B1) as viable alternative fuels for existing compression-ignition diesel engines without hardware modification, while confirming that smoke opacity and fuel consumption remain the principal trade-offs requiring further mitigation.

6.1 Future Scope

- Extending the performance and emission assessment to additional non-edible biodiesel feedstocks and their blends.
- Systematically varying methanol content (0-30% by volume) and testing alternative alcohols (ethanol, propanol, butanol) in ternary blends.
- Applying wavelet or waterfall time-frequency analysis to the vibration data for finer combustion-phase resolution.
- Exploring vibration signatures as an early-warning indicator of engine knock in biodiesel-fuelled engines.

References

1 K. Agarwal, L. M. Das, "Bio-diesel development and characterization for use as a fuel in CI engines," ASME Transactions, vol. 123, pp. 440-447, 2001.

2 Ü. Ağbulut, M. Karagoz, S. Sarıdemir, A. Öztürk, "Impact of various metal-oxide based nanoparticles and biodiesel blends on the combustion, performance, emission, vibration and noise characteristics of a CI engine," Fuel, vol. 270, 117521, 2020.
3 Ü. Ağbulut, S. Sarıdemir, S. Albayrak, "Experimental investigation of combustion, performance and emission characteristics of a diesel engine fuelled with diesel-biodiesel-alcohol blends," Journal of the Brazilian Society of Mechanical Sciences and Engineering, vol. 41, 2019.
A. Taghizadeh-Alisaraei, B. Ghobadian, T. Tavakoli-Hashjin, S. S. Mohtasebi, "Vibration analysis of a diesel engine using biodiesel and petrodiesel fuel blends," Fuel, vol. 102, pp. 414-422, 2012.
4 N. Ozsezen, M. Canakci, "Determination of performance and combustion characteristics of a diesel engine fueled with canola and waste palm oil methyl esters," Energy Conversion and Management, vol. 52, pp. 108-116, 2011.
5 E. Alptekin, "Emission, injection and combustion characteristics of biodiesel and oxygenated fuel blends in a common rail diesel engine," Energy, vol. 119, pp. 44-52, 2017.
A. Datta, S. Palit, B. K. Mandal, "An experimental study on the performance and emission characteristics of a CI engine fuelled with Jatropha biodiesel and its blends with diesel," Journal of Mechanical Science and Technology, vol. 28, pp. 1961-1966, 2014.
6 ASTM International, ASTM D6751-07b, Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels, West Conshohocken, PA, 2008.
A. K. Agarwal, "Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines," Progress in Energy and Combustion Science, vol. 33, pp. 233-271, 2007.
7 P. Babji, B. Rao, A. Kolakoti, "Combustion estimation by cylinder vibration analysis on a supercharged IDI diesel engine — a comparative study with a new fuel as total replacement," International Journal of Recent Trends in Engineering & Research, vol. 3, pp. 110-116, 2017.
8 S. Chauhan, N. Kumar, H. M. Cho, "Performance and emission studies on an agriculture engine on neat Jatropha oil," Journal of Mechanical Science and Technology, vol. 24, no. 2, pp. 529-535, 2010.
9 V. A. Bueno, J. A. Velasquez, L. F. Milanez, "A new engine indicating measurement procedure for combustion heat release analysis," Applied Thermal Engineering, vol. 29, pp. 1657-1675, 2009.
10 Wang, Y. Zhang, Z. Zhong, "Fault diagnosis for diesel valve trains based on time-frequency images," Mechanical Systems and Signal Processing, vol. 22, pp. 1981-1993, 2008.
A. Çalık, "Determination of vibration characteristics of a compression ignition engine operated by hydrogen enriched diesel and biodiesel fuels," Fuel, vol. 230, 2018.
11 M. Canakci, "Combustion characteristics of a turbocharged DI compression ignition engine fueled with petroleum diesel fuels and biodiesel," Bioresource Technology, vol. 98, pp. 1167-1175, 2007.
12 K. Celebi, E. Uludamar, M. Ozcanli, "Evaluation of fuel consumption and vibration characteristic of a compression ignition engine fuelled with high viscosity biodiesel and hydrogen addition," International Journal of Hydrogen Energy, vol. 42, 2017.
13 S. Chauhan, N. Kumar, H. M. Cho, "A study on the performance and emission of a diesel engine fueled with Jatropha biodiesel oil and its blends," Energy, vol. 37, pp. 616-622, 2012.

14 K. Cheikh, S. Awad, K. Loubar, A. Liazid, M. Tazerout, "Experimental assessment of performance and emissions maps for biodiesel fueled compression ignition engine," Applied Energy, vol. 161, pp. 320-329, 2016.