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Research paper

Experimental Investigation and Regression Analysis on the Vibration and Noise Characteristics of an Unaltered Single-Cylinder Constant Speed CI Engine Using Various Biodiesels

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Abstract

The noise and vibrations stemming from combustion in a Compression Ignition (CI) engine directly affect end users. As a renewable energy source, there is potential for it to substitute diesel in CI engines. The present study seeks to explore the sound pressure level (SPL) and vibration characteristics of constant-rpm unaltered CI engines fueled with Nahar, Jatropha and Karanja biodiesel blends. The SPL and vibrations were recorded using, the B&K Photon+ portable measuring system with RTPro software, FFT Analyzer at varying loads and fuelled with diesel D100 and biodiesel blends BDN10, BDN20, BDN30, BDN40, BDN50, BDJ10, BDJ20, BDJ30, BDJ40, BDJ50, BDK10, BDK20, BDK30, BDK40 and BDK50 respectively. Regression analysis models, both linear and non-linear, were established to forecast the association among fuel characteristics and noise-vibration of engine, demonstrating excellent agreement. The findings indicate that, in general, the engine noise and vibration reduced with an increase in biodiesel blends up to 30%. Also, it is observed that for reducing the vibration and SPL of an engine, among all the considered parameters, the engine load is a significant parameter as compared to other parameters such as blending percentage. Furthermore, among the three biodiesels, Nahar is a more impactful biodiesel for reducing the engine's vibration and noise.

***Keywords**: Sound Pressure Level, Vibration, Biodiesel, CI Engine, Regression Analysis.*

1. Introduction

In today's scenario, passenger comfort is the main concern in vehicle design. Vibration is one of the major issues for passenger discomfort [1]. In order to satisfy these issues, the engine-induced vibration could be minimized. The induced engine vibration could be reduced with the accommodation of alternative fuels [2]. Due to its favorable fuel properties, which are similar to diesel, biodiesel has become more attractive to researchers in the last decade, as it can be used with minimal or no engine modifications [3]. The basic advantages of biodiesel include controlling emissions of pollutants such as hydrocarbons (HC), carbon monoxide (CO), and soot particles. However, biodiesel leads to higher nitrogen oxide (NOx) emissions compared to the base fuel [4]. Uludamar et al. [5-7] observed decrease in engine block vibration and average SPL when fuel was used with biodiesel derived from corn, and also developed the regression model. B. Heidary et al. [8] recorded a 12% reduction in total vibration using an alternative fuel in a six-cylinder engine. Erdiwansyah et al. [9] emphasizes a direct relationship between combustion dynamics and the engine's vibration and noise outputs, suggesting smoother combustion at optimized operating conditions. Similarly, Nag et al. [10] described minimal noise and vibration levels for a modified engine compared to its standard counterpart. Recent work by Ong et al. [11] demonstrated that calophyllum inophyllum fuel blends, particularly up to 20%, have the potential to minimize vibration characteristics. Javed et al. [12] employed an artificial neural network to predict vibration (RMS velocities) and identified 20% and 30% blends as having the least vibration. Sharma et al. [13] revealed that differences in combustion characteristics substantially impact engine noise and vibration levels. Further, many researchers have predicted the combustion, vibration and noise level for biodiesel by developing mathematical models [14-17]. From the literature it is observed that vibration and noise level decreased with addition of biodiesel. However, the substantial research is not seen which focused on noise and vibration characteristics of nahar, jatropha and karanja biodiesels. There is also need to perform comparative analysis of these biodiesels.

From the above literature, it is found that many researchers elaborated the study to determine the SPL and vibration of the engine with considerations of alternative fuels. Though the many researchers enlighten thoroughly with varying engine parameters with limited range of biodiesel blends, but still more insights studies are required to estimates the noise and vibration analysis at higher percentage of biodiesel blends as well. Therefore, the current study mainly focused on noise and vibration analysis of unaltered compression ignition (CI) engine on variations of higher rates of biodiesel blend with variations in the engine loads. The novelty of the current study is to investigate accompanied with three different biodiesel fuels. These three biodiesel fuels include nahar, jatropha and karanja. The fuel properties of above blended fuel are changed particularly calorific value, cetane number and density which effect the combustion and hence the vibration. Since, these biodiesels blend shows a greater reduction in emissions like CO, HC, particulate matter and NOx [18–26]. Further, these biodiesel blends are varied from 10% – 50% (i.e., BDN10, BDN20, BDN30, BDN40, BDN50, BDJ10, BDJ20, BDJ30, BDJ40, BDJ50, BDK10, BDK20, BDK30, BDK40 and BDK50). The engine test was performed on unmodified engine with constant speed and variations in loads which are include no load, medium load and full load. Since engine testing is an expensive and time-consuming process, the study is also extended to developed regression models to predict better accuracy of vibration and noise [27-29]. The results of this research have practical significance and contribute to the development of biodiesel for IC engines.

2. Materials and Methods

2.1 Experimental Fuels

The Experimental fuels tested in this study comprised pure diesel (D100) and five different blend ratios for each of three biodiesels: nahar (BDN), jatropha (BDJ), and karanja (BDK). The physicochemical properties of these blends, detailed in Table 1, adhered to ASTM specifications. The preparation and characterization of the biodiesel mixtures were conducted at the Indian Biodiesel Corporation in Baramati, India.

Table1: Fuel Characteristics

Test Fuel	D gm/cc	FP ^{0}C	CV MJ/Kg
D100	0.831	64.00	42.5
BDN10	0.8330	69.00	42.390
BDN20	0.8340	75.00	42.30
BDN30	0.8360	82.00	42.18
BDN40	0.8390	88.00	42.09
BDN50	0.8420	96.00	41.900
BDJ10	0.8310	68.00	42.300
BDJ20	0.8320	72.00	42.11
BDJ30	0.8340	89.00	41.90
BDJ40	0.8360	94.00	41.86
BDJ50	0.8400	99.00	41.70
BDK10	0.8320	70.00	42.40
BDK20	0.8340	86.00	42.31
BDK30	0.8370	95.00	42.16
BDK40	0.8390	101.00	42.03
BDK50	0.8420	107.00	41.94

Were,
D = density in gm/cc, FP = flash point in 0C and CV = calorific value in MJ/Kg

2.2 Experimental Apparatus

Experiments were carried out on a single cylinder, 4S diesel engine operating at constant RPM and featuring a Common Rail Direct Injection (CRDI) fuel system (Fig. 1, Table 2). The test rig was comprehensively instrumented with sensors to record the applied load. Sensor data was transmitted to a computer through a high-speed data acquisition system. Key auxiliary equipment comprised a dedicated control panel containing an air box, dual fuel tanks, a manometer, a fuel metering unit, flow transmitters for air and fuel, a process indicator, and a piezo actuator power supply. Engine and calorimeter cooling water flows were monitored using rotameters. Essential CRDI components integrated into the engine were a programmable ECU, a fuel injector, a common rail assembly, a crank position sensor, a high-pressure fuel pump, and the necessary wiring harness.

Table 2: Engine Configuration

Product	Common Rail Direct Injection VCR Engine
Engine Make	Single cylinder, four stroke, VCR with Open ECU for Diesel mode Kirloskar Make
RPM	1500 Constant
Power	3.5KW
CR range	12-18
Stroke	110 mm
Bore	87.5
CC	661

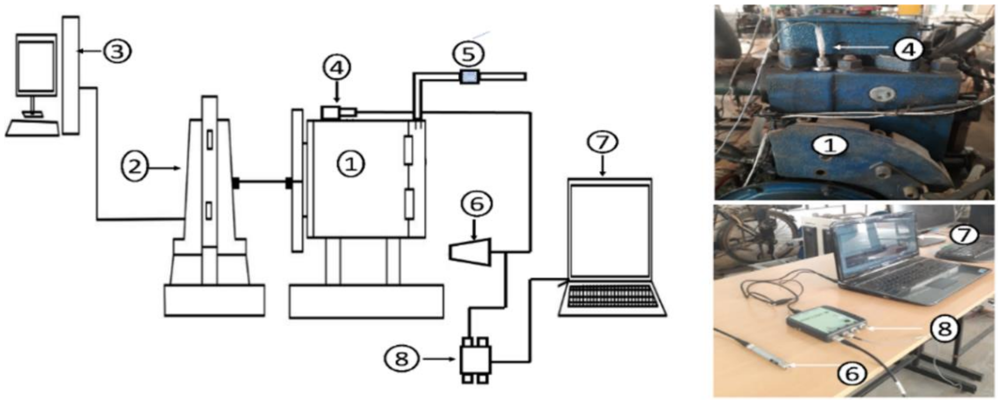

Fig. 1: Experimental Apparatus

(1. Test Engine 2. Dynamometer 3. Performance Measuring System 4. Piezoelectric Shear Accelerometer 5. Air Filter 6. Microphone 7. FFT Signal Recorder 8. FFT Channel)

Vibration measurements were captured using piezoelectric shear accelerometers (Type 4514) with integrated electronics, designed for a broad frequency range and low noise-to-signal ratios. These accelerometers offer adjustable sensitivity settings from 1 to 50 mV/ms² (10–500 mV/g) and feature hermetically sealed, insulated bases with 10-32 UNF top connectors. Three configurations—axial, radial and perpendicular—were installed using threaded studs or adhesive mounts. For acoustic analysis, a prepolarized free field ½" microphone (Type 4188) was positioned 45 cm from the engine surface. The microphone specifications include an open-circuit sensitivity of -30.2 dB (31.1 mV/Pa) at 1000 Hz under standard atmospheric conditions, with free-field sensitivity marginally exceeding pressure sensitivity by 0.15 dB. Acoustic and vibration data were recorded via Brüel & Kjaer's RTPro software and portable instrumentation. The system incorporated a programmable Open ECU, common rail components and synchronized sensors for pressure, crank angle and fluid flow, ensuring precise monitoring of engine parameters. Frequency domain signals were analyzed along the x (longitudinal), y (lateral), and z (vertical) axes. Total vibration acceleration (a_t), combining accelerations in these directions (a_{lon}, a_{lat}, a_{ver}) [30-34], was calculated using equation (1).

$$a_t = \sqrt{a_{ver}^2 + a_{lat}^2 + a_{lon}^2} \tag{1}$$

SPL is a logarithmic degree of sound intensity, expressed in decibels (dB). Its calculation references the threshold of hearing (0 dB), the quietest sound perceivable by an average human ear and defined as 20 micropascals (μPa), as the reference pressure (Pref). The standard formula for SPL in a free field environment is [25, 30]:

$$SPL(dB) = 20 \times log \log_{10}(P/P_{ref}) \tag{2}$$

Here, P represents the calculated sound pressure (rms value) and Pref is the standard reference pressure of 20 μPa for sound in air.

2.3 Test procedure

Engine specifications are detailed in Table 2. A standard stabilization procedure was followed: after filling with pure diesel (D100) or one of the 15 biodiesel blends, the constant-speed engine (1500 rpm) ran for 10 minutes. The fuel tank was drained and cleaned between blends. Testing involved gradually increasing load, with frequency domain signals recorded via an FFT analyzer at no load, medium load, and full load (0-12 kg range) for all fuels. Vibration was measured using piezoelectric shear accelerometers mounted with adhesive on the engine block as shown in Fig. 1. Similarly, sound pressure level (SPL) was measured at the same load points using a prepolarized free-field microphone positioned near the engine block. Both acoustic and vibration data were acquired using Brüel & Kjaer portable equipment running RTPro software.

2.4 Regression analysis

As a fundamental statistical technique, regression analysis quantifies the correlation between dependent and independent variables [35-36]. Linear regression models a straight-line relationship and is simpler to interpret, whereas nonlinear regression accommodates intricate, non-linear dependencies [26]. Selection between these depends on the data characteristics and research objectives. A critical preliminary step involves computing correlation coefficients among relevant parameters. This identifies the optimal input parameters—those exhibiting strong correlations with the target outputs—for forecasting engine noise and vibration. The linear regression model expresses the dependent variable's relationship to the predictors via a linear equation [5, 26]:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \tag{3}$$

For nonlinear regression, the connection between the dependent variable (Y) and the independent variables (X_1, X_2, ..., X_n) is represented by a non-linear mathematical function [5, 26, 29]. Equ. (4) exemplifies a specific power-law form:

$$Y = a_0\left(X_1^{a_1}\right)\left(X_2^{a_2}\right) \dots \left(X_n^{a_n}\right) \tag{4}$$

In this model, Y is the predicted response, X_1, X_2, ..., X_n are the predictor variables, a_0 is a multiplicative constant, and a_1, a_2, ..., a_n are the estimated parameters (exponents) corresponding to each predictor. The values of these parameters a_0, a_1, ..., a_n determine the specific nonlinear relationship modeled.

3. Results and Discussion

3.1 Vibration of the engine

Vibration acceleration data in the frequency domain was acquired directly from the engine block using a Brüel & Kjær (B&K) RT Photon+ FFT analyzer. Measurements were taken at a constant engine romp of 1500 under three distinct load conditions: no load, medium load and full load. The engine was tested using sixteen different fuel types: pure diesel (D100) and blends of nahar (BDN), jatropha (BDJ), and karanja (BDK) biodiesels mixed with diesel at volume percentages ranging from 10% to 50% (BDN10-BDN50, BDJ10-BDJ50, BDK10-BDK50). Key properties of diesel (EN590) and biodiesel (EN14214) fuels are enumerated in Table 1. The central focus was identifying the optimal fuel blend by analyzing their vibrational behavior, noting that engine load significantly influenced both vibration and noise levels (Fig.s 2-4).

Frequency domain signals for all biodiesel blends were compared against pure diesel across load levels (Fig. 2). Nahar blends (BDN) consistently reduced vibration acceleration: by 2.54-11.85% at no/medium load and 12.67-19.97% for BDN10/BDN20 at maximum load. Jatropha blends (BDJ) decreased vibration by 17.15-27.53% at no load (up to BDJ40), while BDJ10/BDJ30 reduced it by 16.62-17.26% at medium load. Most jatropha blends (excluding BDJ40) also lowered vibration by 0.04-5.30% at maximum load. Karanja blends (BDK) showed reductions of 0.29-28.13% at no load (BDK10/BDK20) and 6.34-31.43% at medium/maximum load for BDK10/BDK20/BDK30 compared to diesel.

Vibration acceleration consistently increased with engine load across all 15 blends, peaking at high load and minimizing at no load (Fig.s 5-6). Compared to D100, specific blends significantly reduced vibrations: at no load (BDN10-BDN50, BDJ10-BDJ30, BDK10-BDK20: avg. 0.29-28.13% reduction), medium load (BDN10-BDN50, BDJ10/BDJ30, BDK10-BDK30: avg. 0.49-31.80% reduction), and high load (BDN10/BDN20, BDJ10/BDJ20/BDJ30/BDJ50, BDK10/BDK20/BDK30: avg. 0.49-31.80% reduction). This reduction is attributed to biodiesel's higher oxygen content, promoting more efficient combustion. These results confirm biodiesel blends can effectively lower engine vibrations under specific loads [1-3], aligning with findings from prior studies [4-7].

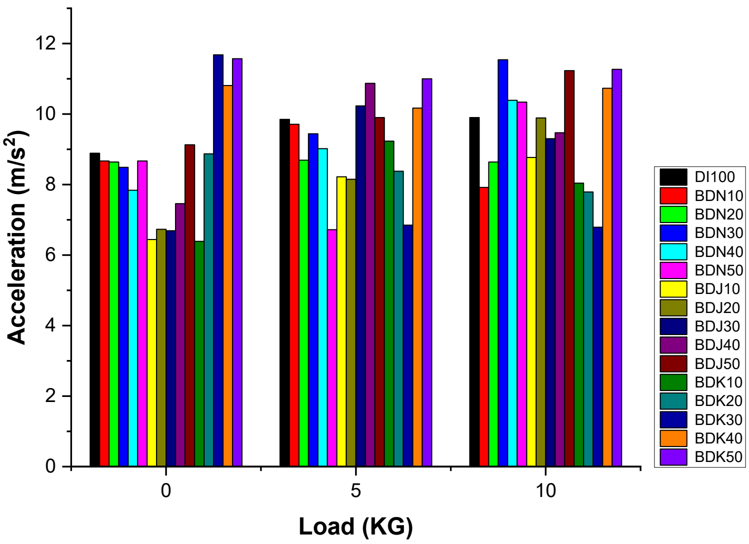

Fig. 2: Engine Acceleration vs. Load: Nahar, Jatropha and Karanja Biodiesel Comparison.

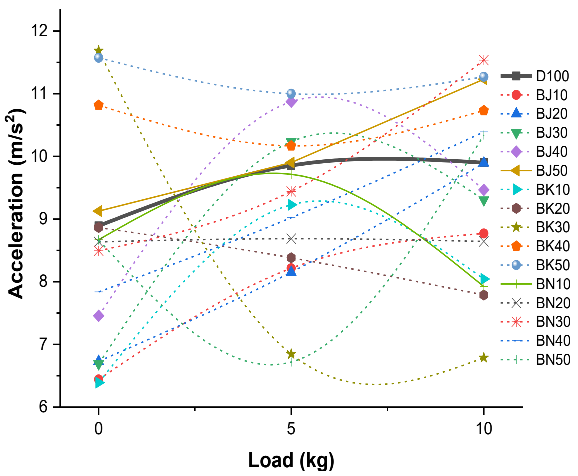

Fig. 3: Acceleration vs. Engine Load: Comparison of Fuel Blends.

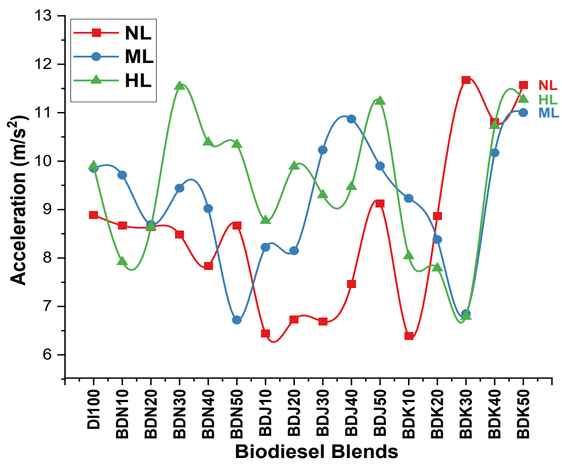

Fig. 4: Acceleration vs. Fuel Blends: Comparison of Load.

3.2 Sound pressure level of the engine

Compression ignition engines represent acoustic complex systems due to the distinct dynamic stresses they impose on structures with differing stiffness, damping properties, and vibrational responses. To meaningfully interpret noise measurements, results were processed using a weighted sound pressure level (SPL) that approximates human auditory perception. The comparative noise data for base fuel and biodiesel blends across test conditions are presented in Fig.s 5-7.

Fig. 5 presents the SPL measured for nahar, jatropha and karanja biodiesel blends alongside diesel across different engine loads (no, medium and full load). Compared to pure diesel, only the BDN20 nahar blend showed a slight increase (0.15%) in SPL, specifically at medium load; all other nahar blends exhibited reductions, with a maximum decrease of 1.92%. For jatropha blends, SPL increased slightly at maximum load for BDJ40 (0.11%) and BDJ50 (0.61%) relative to diesel, while the remaining jatropha blends decreased by up to 1.01%. Similarly, karanja blends were compared to diesel. Karanja blends BDK10, BDK20, and BDK30 all achieved a maximum reduction of 0.93% in sound pressure level at both no load and maximum load. At medium load, reductions ranging up to 0.52% were observed for blends from BDK10 to BDK40. Conversely, some other karanja blends showed a maximum increase of 0.56%.

(Fig.s 6-7) present the SPL results. Under no-load conditions, all listed biodiesel blends (BDN10, BDN20, BDN30, BDN40, BDN50, BDJ10, BDJ20, BDJ30, BDK10, BDK20, BDK30) exhibited reductions in SPL compared to diesel, with decreases of 0.33%, 0.63%, 0.62%, 1.08%, 1.27%, 0.11%, 0.61%, 0.15%, 0.71%, 0.76%, and 0.32%, respectively. At medium load, SPL decreased for blends BDN10, BDN30, BDN40, BDN50, BDJ10, BDJ20, BDJ30, BDJ40, BDJ50, BDK10, BDK20, BDK30, and BDK40 by 0.41%, 1.57%, 1.16%, 1.92%, 0.70%, 0.97%, 1.01%, 0.32%, 0.67%, 0.35%, 0.52%, 0.02%, and 0.05%, respectively. Similarly, under high load, reductions were observed for blends BDN10, BDN20, BDN30, BDN40, BDN50, BDJ10, BDJ20, BDJ30, BDK10, BDK20, and BDK30, with decreases of 0.14%, 0.98%, 0.84%, 1.70%, 1.74%, 0.13%, 0.57%, 0.14%, 0.53%, 0.93%, and 0.24%, respectively. These lower sound pressure levels may be related to reduced engine vibration, a finding consistent with observations by Uludamar et al. [4] and Taghizadeh-Alisaraei et al. [6].

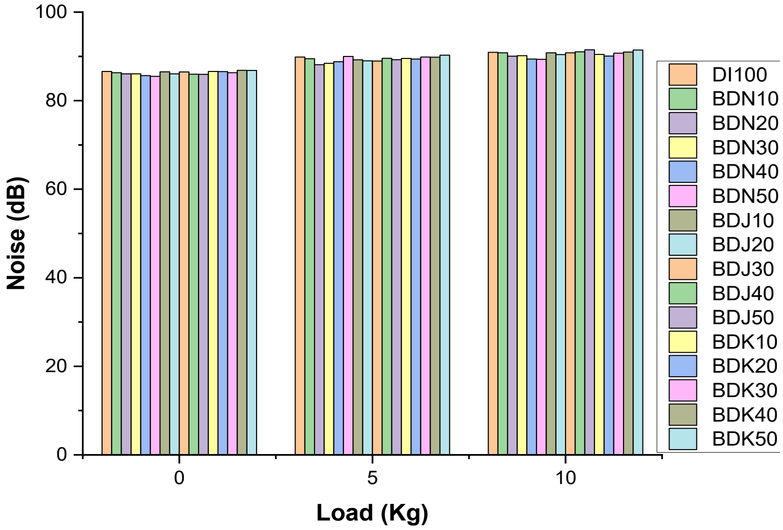

Fig. 5: SPL vs. Load: Nahar, Jatropha and Karanja Biodiesel Comparison.

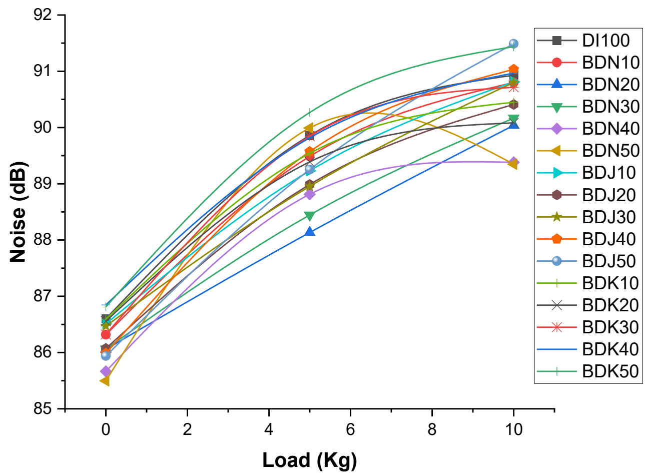

Fig. 6: SPL vs. Engine Load: Comparison of Fuel Blends.

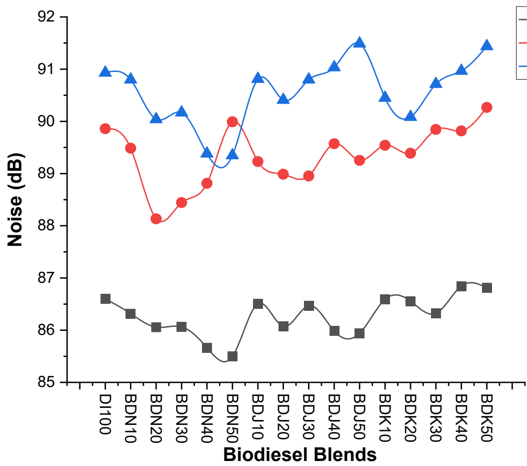

Fig. 7: SPL vs. Fuel Blends: Comparison of Load.

3.3 Model of Linear and non-linear regression analysis

Regression analysis statistically model is relationships between a dependent variable (response) and predictors. Linear regression assumes linearity for simplicity and interpretability, while nonlinear regression accommodates complex patterns with flexible modeling. Selection hinges on data characteristics and study goals. Before initiating analysis, correlation coefficients among all pertinent variables are computed. This step is critical for identifying the most suitable predictors to estimate target outcomes. Parameters demonstrating strong correlations with the predicted values are prioritized for inclusion. In this study, regression analysis proved instrumental in forecasting and elucidating how selected inputs influence the engine's noise and vibration properties.

In this research, both linear and non-linear regression techniques were applied to analyze experimental data, accounting for the inherently random nature of engine vibrations. The study aims to predict two critical parameters in internal combustion engines: vibration levels and sound pressure. Input variables, calorific value, density, flash point and load (categorical), were selected using XLSTAT software. These

parameters were prioritized due to their substantial impact on combustion dynamics, which directly govern noise and vibration in compression ignition engines. Their strong correlation with combustion behaviour underscores their importance in shaping the engine's acoustic and vibrational outputs.
For statistical evaluation, the widely used STATA software facilitated regression analysis, data management and visualization. The results, summarized in subsequent equations, reveal key associations among the chosen input variables and the engine's vibration and noise characteristics, offering actionable insights for understanding and mitigating noise and vibration in engine systems.
For nahar biodiesel,

$$Vibration = 26.77 + CV(-62.78) + D(113.52) + FP(-1.073) + L(0.5997\ if\ With\ Load, -0.0026\ if\ No\ Load) \quad (5)$$

$$lnVibration = 881.10 - 225.97 * lnCV + 10.2043 * lnD - 7.2380 * lnFP + L(0.081\ if\ With\ Load, -0.0028\ if\ No\ Load) \quad (6)$$

$$Noise\ dB = 96 + CV(0.314) + D(-21.00) + FP(-0.322) + L(-0.976\ if\ With\ Load, -4.026\ if\ No\ Load) \quad (7)$$

$$lnNoise\ dB = 2.515 + 0.5387 * lnCV - 0.2073 * lnD - 0.0157 * inFP + L(-0.01090\ if\ With\ Load, -0.045\ if\ No\ Load) \quad (8)$$

For jatropha biodiesel,

$$Vibration = 120.74 + CV(-6.060) + D(183.93) + FP(-0.118) + L(-0.258\ if\ With\ Load, -2.442\ if\ No\ Load) \quad (9)$$

$$lnVibration = 110.71 - 27.12 * lnCV + 15.4986 * lnD - 0.9656 * lnFP + L(-0.0302\ if\ With\ Load, -0.2937\ if\ No\ Load) \quad (10)$$

$$Noise\ dB = -8.99 + CV(2.120) + D(9.16) + FP(0.039) + L(-1.710\ if\ With\ Load, -0.0532\ if\ No\ Load) \quad (11)$$

$$lnNoise\ dB = 1.0290 + 0.9015 * lnCV + 0.1290 * lnD + 0.0306 * lnFP + L(-0.0190\ if\ With\ Load, -0.0532\ if\ No\ Load) \quad (12)$$

For karanja biodiesel,

$$lnVibration = -190.89 + CV(4.8315) + D(-13.92) + FP(0.059) + L(-0.3639\ if\ With\ Load, -0.3599\ if\ No\ Load) \quad (13)$$

$$lnVibration = -136.03 + 35.69 * lnCV - 2.5382 * lnD + 0.868 * lnFP + L(-0.065\ if\ With\ Load, -0.0643\ if\ No\ Load) \quad (14)$$

$$Noise\ dB = 176 + CV(-1.93) + D(-1.98) + FP(-0.035) + L(-0.96\ if\ With\ Load, -4.106\ if\ No\ Load) \quad (15)$$

$$lnNoise\ dB = -1.4347 + 1.5429 * lnCV + 0.1678 * lnD + 0.045 * lnFP + L(-0.0106\ if\ With\ Load, -0.046\ if\ No\ Load) \quad (16)$$

Where CV: calorific value, D: density, FP: flash point, L: is load.

Table 3: Statistical comparison of linear and non-linear regression models.

		R square	Adj. R square	MAPE (%)	*p*-value
			Nahar		
Vibration	Linear	0.698	0.531	8.7637	0.0308
	Non - Linear	0.655	0.463	4.6654	0.0524
Noise	Linear	0.975	0.962	0.2712	0.0000
	Non - Linear	0.976	0.964	0.0594	0.0000
			Jatropha		
Vibration	Linear	0.816	0.715	0.6160	0.0039
	Non - Linear	0.829	0.735	2.1639	0.0029
Noise	Linear	0.985	0.976	0.2201	0.0001
	Non - Linear	0.983	0.975	0.0491	0.0001
			Karanja		
Vibration	Linear	0.761	0.628	3.3512	0.0120
	Non - Linear	0.755	0.618	1.9663	0.0134
Noise	Linear	0.965	0.946	0.2901	0.0000
	Non - Linear	0.967	0.948	0.0636	0.0000

Equ. (5), (7), (9), (11), (13) and (15) use linear computational approaches to forecast the engine's vibration and SPL by substituting input variables into the formulas. In contrast, Equ. (6), (8), (10), (12), (14) and (16) rely on nonlinear methodologies to achieve the same objective. The correlation coefficient (R) and absolute percentage error (MAPE) served as primary performance indicators to assess model accuracy and reliability (Table 3).
Analysis of the collected data revealed challenges in definitively characterizing the model's behavior, a conclusion further supported by adjusted R^2 values. However, both linear and non-linear regression approaches demonstrated comparable precision in predicting vibration and sound pressure levels, yielding results within acceptable error margins. A comparative evaluation of model performance, based on actual versus predicted vibration and noise data (Fig.s 8–9), identified the non-linear regression model for vibration and the linear regression model for noise as the optimal choices for the dataset. These findings are mathematically represented in Equ. (17–20) and summarized in Table 4, highlighting the suitability of each model for capturing the distinct dynamics of vibration and acoustic outputs in the experimental framework.

$$Vibration = 120.74 + CV(-6.060) + D(183.93) + FP(-0.118) + L(-0.258\ if\ With\ Load, -2.442\ if\ No\ Load) \quad (17)$$

$$lnVibration = 110.71 - 27.12 * lnCV + 15.4986 * lnD - 0.9656 * lnFP + L(-0.0302\ if\ With\ Load, -0.2937\ if\ No\ Load) \quad (18)$$

$$Noise\ dB = -8.99 + CV(2.120) + D(9.16) + FP(0.039) + L(-1.710\ if\ With\ Load, -0.0532\ if\ No\ Load) \quad (19)$$

$$lnNoise\ dB = 1.0290 + 0.9015 * lnCV + 0.1290 * lnD + 0.0306 * lnFP + L(-0.0190\ if\ With\ Load, -0.0532\ if\ No\ Load) \quad (20)$$

Table 4: Performance comparison of linear and non-linear regression

		R square	Adj. R square	MAPE (%)	*p* - value
Vibration	Linear	0.816	0.715	0.6160	0.0039
	Non - Linear	0.829	0.735	2.1639	0.0029
Noise	Linear	0.985	0.976	0.2201	0.0001
	Non - Linear	0.983	0.975	0.0491	0.0001

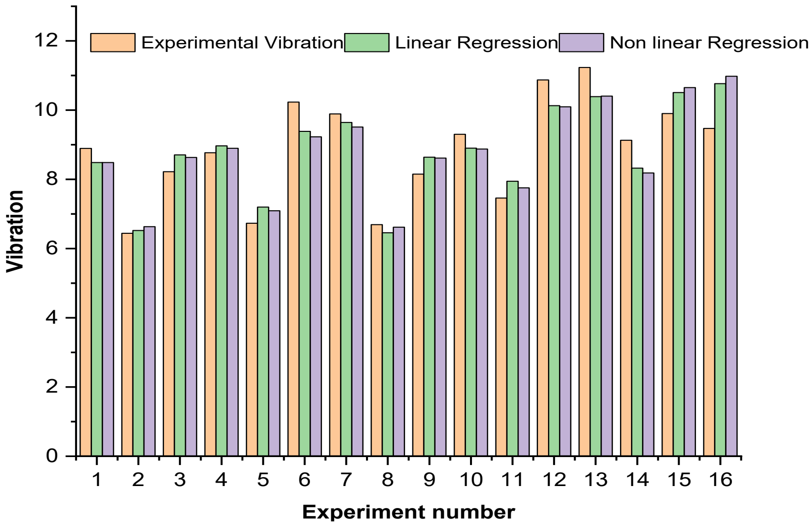

Fig. 8: Actual and predicted vibration

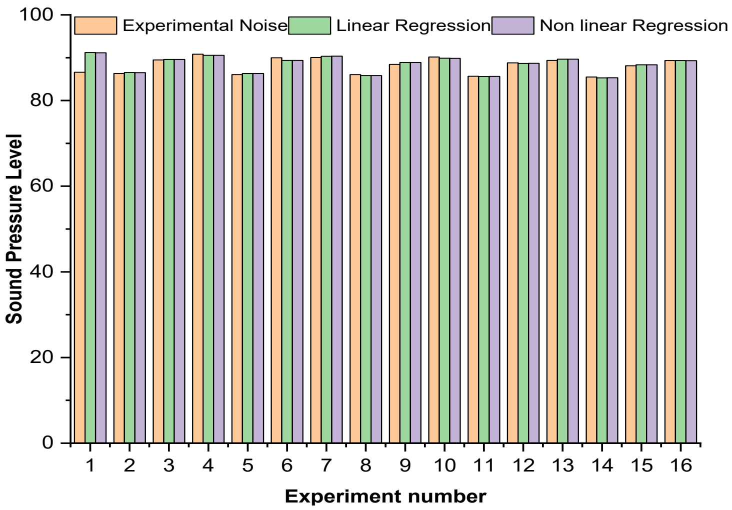

Fig. 9: Actual and predicted SPL

The analysis concludes that both linear and non-linear regression approaches yield reliable forecasts of vibration and SPL, with accuracy falling within acceptable thresholds.

4. Conclusions

This study evaluated the effects of nahar, jatropha, and karanja biodiesel fuels on the noise and vibration characteristics of an unaltered CI engine operating at constant speed. The mathematical models were developed to forecast engine vibration and sound pressure levels. Key conclusions drawn from the experimental observations include:

- Engine load significantly impacted vibration acceleration and SPL. Using pure diesel, vibration acceleration increased by 10.17% and SPL by 4.76% at maximum load compared to no load.
- Biodiesel blending alters key fuel characteristics, influencing combustion characteristics and consequently affecting engine block vibration and sound pressure level.
- Nahar biodiesel blends (BDN10-BDN50) consistently reduced vibration and sound pressure levels compared to diesel at low and medium loads, with maximum reductions of 31.80% (vibration) and 1.92% (sound pressure).
- Jatropha biodiesel blends (BDJ10-BDJ20) reduced vibration and sound pressure levels across all loads, achieving maximum reductions of 27.55% (vibration) and 0.97% (sound pressure) versus diesel.
- Karanja biodiesel blends (BDK10-BDK20) also reduced vibration and sound pressure levels at all loads, with maximum reductions of 28.13% (vibration) and 0.93% (sound pressure) relative to diesel.
- Statistically acceptable prediction accuracy for engine vibration and sound pressure levels was achieved with both linear and non-linear regression.

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