



Experimental Investigation of Eugenol Bio-Additive on Engine Performance of RON 92 Gasoline

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Abstract. This study investigates whether very small additions of eugenol can modify the performance of a commercial RON 92 gasoline in a spark-ignition engine. Eugenol was selected as a renewable oxygenated compound because its molecular structure can influence fuel oxidation and combustion behavior. Three fuels were evaluated: unblended RON 92 gasoline (E0), gasoline containing 0.1% v/v eugenol (E0.1), and gasoline containing 0.5% v/v eugenol (E0.5). Tests were conducted on a 150 cc four-stroke motorcycle equipped with EFI and CVT and operated on a chassis dynamometer. Power and torque were recorded over the engine-speed range, and each fuel was tested in triplicate before the mean values were analyzed. Both eugenol blends outperformed the base fuel over most of the tested range. The largest peak power was obtained with E0.5, reaching 8.85 HP at 7,800 rpm, approximately 11% above E0. The highest torque, 9.78 Nm at 5,700 rpm, was produced by E0.1. The results suggest that low-dose eugenol blending can improve the conversion of fuel energy into useful engine output. Further work should examine broader blend ratios, direct combustion parameters, storage stability, and long-term engine durability.

Keywords: Chassis Dynamometer; Engine Performance; Eugenol; RON 92 Gasoline; Spark-ignition Engine.

1 Introduction

Road transport continues to depend heavily on fossil-derived fuels and consequently contributes to greenhouse-gas emissions and broader environmental impacts (Lindstad et al., 2023; Mokhtar et al., 2025; Zhang et al., 2023). Spark-ignition (SI) engines remain widely used, especially in developing economies, so improving gasoline combustion remains relevant to both energy efficiency and emission control. One approach is to reformulate gasoline with renewable oxygen-bearing compounds. By introducing chemically bound oxygen into the fuel, such additives can support oxidation reactions and may promote more complete combustion, although the magnitude of the benefit depends on fuel chemistry and engine operating conditions (Gupta et al., 2024; Musyaroh et al., 2024; Xu et al., 2022). Recent engine studies likewise indicate that oxygenated bio-components can alter combustion and performance without requiring major changes to conventional gasoline-engine hardware (Ghazali et al., 2025).

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A wide range of renewable blending components has already been explored for gasoline engines, from lower alcohols to compounds obtained from essential oils (Altarazi et al., 2022; Kale & Krishnasamy, 2024). Ethanol and butanol are attractive because they are renewable and contain oxygen, but their use can also alter properties such as heating value, volatility, miscibility, and phase stability. These limitations have encouraged investigation of alternative bio-derived molecules. Limonene, citronella-derived compounds, and other oxygenated constituents of essential oils have therefore received increasing attention. Available studies show that such additives can influence combustion and emissions; however, the response of engine power is not universal and varies with both molecular characteristics and blending level (Alsaheb et al., 2025; Gupta et al., 2024; Paloboran et al., 2024; Suarta et al., 2025).

Eugenol is one candidate in this group. It is a phenolic compound commonly obtained from clove oil and contains oxygenated functional groups within an aromatic molecular structure. These features make eugenol relevant for gasoline blending because they can affect oxidation chemistry, resistance to knock, and the way energy is released during combustion. Prior work has reported favorable effects of eugenol on octane-related behavior, combustion characteristics, fuel consumption, and exhaust emissions under selected test conditions (Musyaroh et al., 2024; Suarta et al., 2025). Its potential benefit, however, must be considered together with its physical properties, because changes in blend volatility and evaporation behavior may become important as the eugenol fraction increases.

Although eugenol has been examined as a renewable fuel additive, evidence from direct motorcycle dynamometer testing at very low blend fractions is still limited. Many previous investigations emphasize emissions or fundamental combustion behavior rather than simultaneous changes in power and torque under a realistic vehicle test configuration. The present work therefore evaluates commercial RON 92 gasoline containing 0, 0.1, and 0.5% v/v eugenol, designated E0, E0.1, and E0.5, respectively. All fuels were tested on the same chassis-dynamometer setup and under the same operating procedure so that differences in output could be attributed primarily to fuel composition. The study focuses on how these low eugenol concentrations modify the power-speed and torque-speed responses of the engine and on identifying the blend that gives the most favorable performance within the investigated range.

The contribution of this work is the experimental characterization of low-concentration eugenol–RON 92 blends using power and torque measured directly on a motorcycle chassis dynamometer. By concentrating on blend levels below 1% v/v, the study provides preliminary performance data for a fuel-modification strategy that can be applied without altering the engine hardware.

2 Methodology

2.1 Fuel Preparation

Commercial RON 92 gasoline served as the reference fuel, while eugenol of at least 99% purity was used as the bio-additive. The blends were prepared volumetrically to examine the response of the engine to small eugenol additions. E0 contained only the base gasoline; E0.1 contained 0.1% v/v eugenol; and E0.5 contained 0.5% v/v eugenol.

The composition and measured/calculated properties of these fuels are summarized in Table 1.

Each blend was mechanically stirred for approximately 15 min at room temperature before testing. This procedure was used to obtain a uniform mixture, after which the fuel was kept in a sealed glass container to limit evaporative losses. Research octane number was measured in the Energy and Environmental Laboratory using a Shatox SX-300 instrument. Blend density was estimated from the volume fraction and density of each constituent using Eq. (1).

$$\rho_{mix} = (\sum \rho_i V_i) / \sum V_i \tag{1}$$

where:

(ρ_i) = density of fuel component (i)

(V_i) = volume of fuel component (i)

Table 1. Fuel Composition and properties used in the experiment

Fuel code	RON 92 gasoline (%v/v)	Eugenol (%v/v)	Blend RON	Density
E0	100	0	92.9	0.745
E0.1	99.9	0.1	93	0.7453
E0.5	99.5	0.5	93.4	0.746

2.2 Experimental Setup

Performance measurements were obtained from a 150 cc, four-stroke SI motorcycle engine equipped with electronic fuel injection and a continuously variable transmission. Before data collection for each fuel, the engine was operated until its condition stabilized. The same engine configuration, ignition setting, lubricant, test equipment, and ambient test environment were maintained throughout the experimental program to improve comparability among E0, E0.1, and E0.5.

The motorcycle was tested on the chassis dynamometer described in Table 2. Measurements were carried out at wide-open throttle (WOT), with engine speed increased progressively through the usable operating range. During each run, the dynamometer system continuously acquired rotational speed and brake-power data. Applying an unchanged test sequence to every fuel provided a common basis for comparing the effect of eugenol concentration on engine output.

Table 2. Dynamometer Specifications

Equipment type	Super Dyno 50Lb series
Maximum power	500 HP
Maximum torque	100 ft Lbs
Maximum speed	200 Km·h ⁻¹
Speed sensor	BRT software control and interface
AFR sensor	Bosch LSU 4.9 ADV
Drum speed accuracy	±1/100 Mile·h ⁻¹

Drum diameter	305 mm
Equipment type	Super Dyno 50Lb series
Maximum power	500 HP

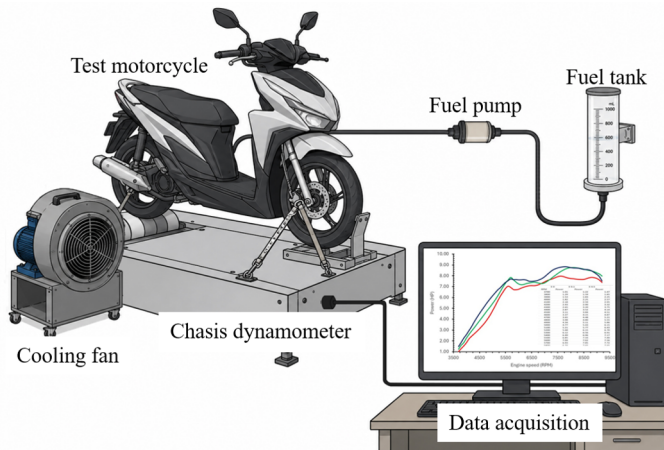


Figure 1. Experimental setup of the chassis dynamometer test.

2.3 Experimental Procedure

The test sequence was organized to minimize carryover between fuels and to provide repeatable measurements. Before a new fuel was evaluated, the standard fuel supply was connected to an external pump and graduated reservoir. The engine was allowed to run long enough for the selected test fuel to replace the previous fuel throughout the supply line and injection system.

The motorcycle was then secured on the chassis dynamometer and operated at WOT. Engine speed was swept from the lower operating region toward the maximum test speed while the dynamometer software recorded the corresponding performance data.

Three complete runs were performed for each fuel formulation under the same test conditions. For subsequent comparison, the three measurements were averaged so that isolated run-to-run fluctuations had less influence on the reported trends.

2.4 Data Analysis

Brake power was the main performance variable used in the quantitative comparison. For every fuel, dynamometer power was evaluated as a function of engine speed, and the maximum value was identified from the corresponding power curve. The relative change in peak power for an eugenol blend was then referenced to the peak value of E0 using Eq. (2).

$$\Delta P = ((P_i - P_0) / P_0) \times 100\% \quad (2)$$

Where:

(P_i) = maximum engine power of the blended fuel (HP)

(P_0) = maximum engine power of neat RON 92 gasoline (HP)

Power-speed curves were used to compare E0, E0.1, and E0.5 over the tested engine-speed range. The plotted values represent the averages of three repeated runs for each formulation. This approach allows the influence of eugenol concentration to be assessed from both the overall curve shape and the change in maximum engine power.

3 Result and Discussion

3.1 Result

Engine Power Characteristics. Figure 2 compares the power-speed responses obtained with the three fuels. All curves rise strongly from low engine speed and reach their highest values in the upper-middle portion of the test range before declining near the highest speeds. Despite this common pattern, both eugenol-containing fuels generally lie above E0. E0.5 gives the strongest high-speed response, while E0.1 follows a similar trend with a slightly different peak position.

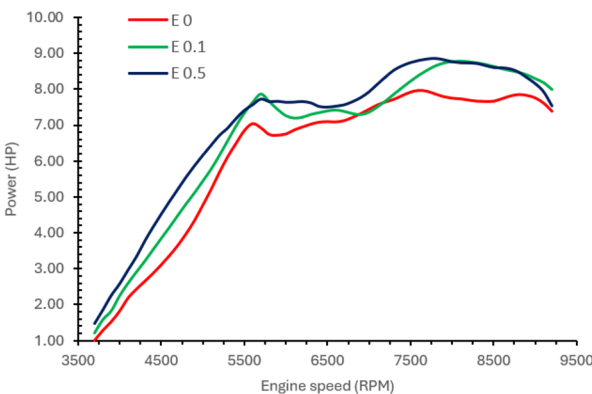


Figure 2. The power generated by the dynamometer test results

Engine Torque Characteristics. The torque curves in Figure 3 also show a positive response to eugenol addition. E0 reaches a maximum of 8.92 Nm at 5,600 rpm. The peak increases to 9.78 Nm at 5,700 rpm for E0.1, whereas E0.5 produces 9.61 Nm at 5,700 rpm. Thus, the 0.1% blend provides the highest measured peak torque, while the 0.5% blend remains above the base-fuel maximum.

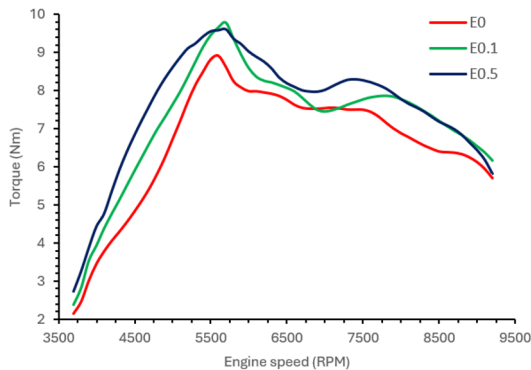


Figure 3. The torque generated by the dynamometer test results

3.2 Discussion

The power data indicate that even small additions of eugenol altered engine output. E0.5 achieved the highest measured power, approximately 8.85 HP at 7,800 rpm, followed by E0.1 at about 8.77 HP at 8,100 rpm; E0 reached approximately 7.97 HP at 7,600 rpm. Relative to the base fuel, the E0.5 peak represents an increase of about 11%. A plausible explanation is that the oxygen-containing structure of eugenol supports oxidation reactions during combustion and can contribute to a faster or more stable energy-release process under suitable mixture conditions (Syarifudin; et al., 2025). Similar studies of oxygenated fuels have shown that their performance effect depends on the balance between chemical advantages and changes in fuel properties (Larsson et al., 2021). Within the concentration range examined here, 0.5% v/v gave the most favorable peak-power result.

The torque response shows that the concentration producing the largest peak power was not the one producing the largest peak torque. Around the medium-speed region, E0.1 slightly exceeds E0.5, whereas the two eugenol blends become closer at higher speeds. This difference may reflect the competing chemical and physical effects of adding eugenol. At 0.1% v/v, the additive can influence combustion chemistry while producing only a very small change in the bulk properties of the gasoline. Increasing the eugenol fraction to 0.5% v/v raises the blend density slightly, as shown in Table 1, and also introduces more of a component whose boiling point is approximately 254 °C (Hadi et al., 2021). The higher-boiling constituent can reduce overall evaporation tendency and may influence spray preparation, particularly when the available time for vaporization is short. Consequently, E0.5 can deliver the best peak power at higher engine speed while E0.1 retains a small torque advantage around the torque-peak region. The observed response is therefore consistent with a trade-off between oxygen-assisted combustion and the progressive influence of eugenol on mixture volatility and atomization.

A further qualitative feature of Figures 2 and 3 is the comparatively smooth response of the eugenol blends over much of the operating range. This pattern is consistent with more uniform energy release from cycle to cycle, but the present chassis-dynamometer measurements do not directly quantify combustion variability, misfire frequency, or in-

cylinder pressure. Confirmation of those mechanisms would require cylinder-pressure acquisition or other combustion-resolved diagnostics. The current results can therefore establish the performance trend, while the underlying stability mechanism should be treated as a hypothesis for future testing.

4 Conclusion

This work examined the effect of adding 0.1 and 0.5% v/v eugenol to commercial RON 92 gasoline using a 150 cc gasoline motorcycle tested on a chassis dynamometer. Within the investigated concentration range, both blends changed the power and torque characteristics relative to the unblended fuel.

E0.1 produced the largest peak torque, 9.78 Nm at 5,700 rpm, whereas E0.5 generated the largest peak power, 8.85 HP at 7,800 rpm. The latter value was approximately 11% higher than the maximum power obtained with E0. These results show that the optimum eugenol fraction depends on the selected performance metric rather than following a single monotonic concentration trend.

The measured improvements are consistent with a beneficial contribution from the oxygenated structure of eugenol, while the difference between E0.1 and E0.5 also indicates that changes in fuel physical properties cannot be neglected. Because the present experiment measured chassis-dynamometer output rather than in-cylinder combustion, the proposed explanations concerning oxidation, flame development, evaporation, and combustion stability should be verified with combustion-resolved measurements.

Future studies should extend the eugenol concentration range and include cylinder-pressure analysis, heat-release calculations, fuel-property measurements, storage tests, and durability assessment. Such measurements would clarify why the blend giving the best torque differs from the blend giving the best peak power and would help determine whether the observed gains remain stable during long-term use.

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