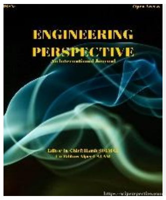

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Effect of Different Benzoylthiourea Additives to Gasoline on Engine Noise and Vibration in a Spark Ignition Engine

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ABSTRACT

This study investigates the effects of dichloromethane (DCM) and benzoylthiourea derivatives (LH1 and LH2) at concentrations of 25 ppm, 50 ppm, and 100 ppm on engine noise and vibration across various load conditions. The results reveal that noise and vibration levels increased with engine load for all fuel blends, with significant variations depending on the additive type and concentration. Adding DCM to gasoline caused slight increases in both noise (up to 1.29%) and vibration (up to 6.14%) due to its higher density and altered combustion dynamics. LH1 consistently increased noise and vibration levels, with the highest increases observed at 100 ppm (6.77% noise and 23.38% vibration at no load), likely due to its volatile nature and destabilizing effects on combustion. Conversely, LH2 significantly reduced noise and vibration, particularly at 25 ppm and 50 ppm concentrations. At 100 ppm, LH2 reduced noise by 1.98% and vibration by 6.85% at full load compared to gasoline, attributed to its superior knock resistance and stabilizing effects on combustion. The findings highlight LH2 as a promising additive for applications requiring reduced engine noise and vibration, particularly at higher loads. In contrast, LH1's tendency to amplify noise and vibration suggests a need for optimization before practical implementation. This study underscores the critical role of additive composition and concentration in influencing engine performance, providing valuable insights for developing fuel blends with improved acoustic and operational characteristics.

Keywords: Benzoylthiourea; Dichloromethane; Engine noise, Engine vibration; Gasoline engine

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1. Introduction

The growing demand for high-performance internal combustion (IC) engines has intensified efforts to optimize engine efficiency [1-4]. However, alongside advancements in engine performance, addressing challenges such as noise and vibration, both of which have mechanical and environmental implications, remains a critical concern. Excessive noise and vibration not only diminish passenger comfort but also contribute to environmental noise pollution. Moreover, they accelerate engine wear and adversely affect operational efficiency. These challenges become increasingly significant as modern engines aim for higher power outputs and improved fuel efficiency while adhering to stricter environmental regulations [5-8].

Engine noise and vibration are complex phenomena influenced by a variety of factors, including combustion processes, mechanical imbalances, and fuel properties. Researchers are actively exploring strategies to mitigate these effects, with one promising approach being the modification of fuel composition through alternative fuel additives. These additives have the potential to alter combustion dynamics, providing a means to reduce noise and vibration while preserving or even enhancing engine performance. Given the significance of noise and vibration in IC engines, fuel additives have become a key area of focus for researchers, particularly in recent years.

The literature includes significant studies on the impact of fuel additives used in IC engines on engine noise and vibration levels. Elkelawy et al. conducted a review study examining the effects of organic compound additives on biodiesel fuel blends to assess diesel engine vibration and noise characteristics. The study reported reductions of up to 5% in engine vibration levels and up to 7% in noise levels [9]. Bharath and Selvan carried out experimental research to evaluate the impact of isobutanol addition to methanol-gasoline blends on the noise, vibration, and emission characteristics of an unmodified automotive spark ignition (SI) engine. Their findings indicated that the blended fuels produced higher overall noise levels but lower accelerations in the vertical and longitudinal directions compared to pure gasoline [10]. Wirawan et al. performed experimental analyses to investigate the effect of adding methanol as a non-fossil fuel mixture to RON 88 gasoline. The results showed that the highest engine vibration occurred in the vertical radial direction, measuring 36 m/s^2 with methanol and 34 m/s^2 without methanol, at engine speeds of 1200 to 1600 rpm. Engine noise was higher for methanol-blended fuel, with a maximum value of 86.4 dB, compared to 85.7 dB for pure gasoline [11]. Ağbulut et al. studied the effects of blending waste cooking oil methyl ester with various metal oxide-based nanoparticles on the emissions, performance, vibration, and noise characteristics of a single-cylinder diesel engine. The results suggested that the addition of nanoparticles to B10 slightly reduced noise and vibration levels [12]. Xu et al. investigated the vibration, wear, and emission characteristics of three types of composite additives with detergent and synergist functions in a diesel engine. Their findings revealed that Type III additives exhibited moderate combustion intensity and mechanical stress, demonstrating an effective capability for vibration control, with a slight 7.6% reduction in mechanical vibration during the running-in period [13]. Wei et al. found that methanol-diesel blends, particularly those incorporating nanoparticle additives, can increase maximum in-cylinder pressure and slightly shorten the ignition delay, both of which influence noise and vibration. However, these blends also tend to result in higher NO_x emissions [14]. Similarly, Rao et al. observed that methanol and biodiesel blends in diesel engines exhibit smoother combustion and reduced vibration, suggesting improved torque conversion and reduced combustion heterogeneity [15]. Sani et al. conducted an experimental study on a four-cylinder gasoline engine powered by a methanol-gasoline fuel blend. Their results revealed that the methanol-gasoline mixture produced the highest levels of vibration and noise within the 1200–1400 rpm range, whereas pure gasoline exhibited the lowest vibration and noise levels between 1000 and 1400 rpm. The tests further demonstrated that the engine's operation with the methanol-gasoline blend led to significant frequency variations, ranging from 148 to 173 Hz [16]. Sharma et al. carried out a study using a single-cylinder gasoline direct injection (GDI) research engine to examine its noise and vibration characteristics. Their findings revealed that methanol-gasoline blends produced notably higher in-cylinder pressure, increased heat release rates, greater rates of pressure rise, and elevated cumulative heat release compared to pure gasoline. These factors had a significant impact on the engine's noise and vibration behavior [17]. Borg et al. investigated methods to reduce noise and vibration in the high-pressure fuel system of a GDI system, focusing on optimizing the mechanical design features of the outlet valve. Their findings demonstrated noise reductions ranging from 2 to 6 dBA across various characteristic frequency levels of the GDI system. [18]. Keskin investigated the vibration characteristics and noise emissions of a two-stroke SI engine fueled with ethanol-gasoline blends. The study revealed significant changes in engine vibration behavior at 1500 and 2500 rpm when using the blended fuels. The vibration amplitudes and noise emissions of the engine exhibited an increasing trend compared to those observed with pure gasoline [19]. Faraji et al. examined the impact of magnetized ethanol-gasoline fuel blends on the vibration and sound characteristics of a single-cylinder gasoline engine. Their findings showed that the highest average sound pressure level (88.41 dB) was observed with pure gasoline at a magnetic intensity of 7000 G, while the lowest value (78.94 dB) was recorded with a 10% ethanol blend and a magnetic intensity of 5300 G. Additionally, vibration levels were found to decrease as the ethanol concentration increased up to 10% [20]. Uyumaz et al. carried out an experimental investigation to evaluate the impact of adding lacquer thinner to gasoline on the performance and emission characteristics of a SI engine. The findings revealed a reduction in HC emissions by 3.4%, 5.6% and 12.13% with lacquer thinner concentrations of 10%, 20% and 30% (LT10, LT20, and LT30), respectively, compared to pure gasoline. Similarly, CO emissions decreased by 1.09%, 2.18% and 3.56% for the same lacquer thinner concentrations [21]. Aydoğan performed a study to explore the influence of ethanol on the combustion, performance, and emission characteristics of a single-cylinder homogeneous charge compression ignition (HCCI) engine. The results demonstrated a reduction in HC emissions with the use of a fuel blend comprising 15% ethanol and 85% n-heptane [22]. Overall, fuel additives have the potential to enhance engine performance and mitigate unavoidable emissions, although they may slightly increase noise and NO_x emissions. Additionally, blends containing biofuels have shown promise in reducing vibration and noise, making them attractive candidates for achieving cleaner and quieter engine operations.

In recent years, extensive research has been conducted on fuel additives with varied chemical compositions for use in IC engines. These studies focus on improving combustion efficiency and engine performance by employing fuel additives with high oxygen content. Among the chemicals being explored are benzoylthiourea and its derivatives, which have garnered significant attention for their contributions to advancements in medicinal and coordination chemistry [23–25]. Thiourea derivatives and their transition metal complexes exhibit a wide array of biological and medicinal properties, including antibacterial, antifungal, antiviral, and antitumor activities [26,27].

Numerous studies on the use of benzoylthiourea derivatives as fuel additives have been documented in the literature. While limited, research suggests that benzoylthiourea derivatives can enhance fuel properties in IC engines. Keskin et al. investigated the effects of adding bis-(N,N-dimethyl-N'-2-chlorobenzoylthioureato) palladium (II) (PdL_2) and bis-(N,N-dimethyl-N'-2-chlorobenzoylthioureato) nickel (II) (NiL_2) complexes as metal-based additives to diesel fuel. The findings revealed that while PdL_2 and NiL_2 did not significantly alter the fundamental fuel properties, they reduced the pour point and increased the flash point of the diesel. Emission reductions were significant, with CO decreasing by 68.15%, NOx by 34.93%, and smoke by 50.24%. Additionally, the brake-specific fuel consumption (BSFC) decreased by approximately 7.75% [28]. In another study, Keskin et al. examined the impact of diesel-biodiesel blends containing palladium-based and acetylferrocene additives on engine performance and emissions. Bis-(N,N-dimethyl-N'-2-chlorobenzoylthioureato) palladium (II) (PdL_2) was synthesized as a palladium-based additive and added to the blended fuels at a concentration of 25 ppm. The study assessed the additives' effects on emissions, performance, and vibration. The results indicated that the viscosity, density, and pour point of the blended fuels increased, while the cetane number and calorific value decreased. Although the metal-based additives did not significantly affect cylinder pressure, they substantially reduced particulate matter (PM) and CO emissions by up to 60.07% and 51.33%, respectively [29]. Gao et al. explored the application of urea-thiourea complexation as a method to enhance the octane number of FCC gasoline by extracting n-alkanes. The addition of thiourea proved highly effective in isolating n-alkanes from FCC gasoline, markedly decreasing their concentration in the remaining liquid phase. Their findings highlighted the remarkable efficacy of the urea-thiourea complexation process in improving the octane quality of gasoline [30].

Thiourea and its derivatives play a crucial role in the fields of medicine and healthcare. This study focuses on examining the effects of two specific compounds, N-((5-chloropyridin-2-yl)carbamothioyl)furan-2-carboxamide (HL1) and N-((2-chloropyridin-3-yl)carbamothioyl)thiophene-2-carboxamide (HL2) on the noise and vibration levels of a gasoline-powered engine. These benzoylthiourea derivatives and their complexes with cobalt(II), nickel(II), and copper(II) were synthesized following the method previously reported by Yeşilkaynak et al. [31,32]. For experimental evaluation, the additives were dissolved in dichloromethane and blended with gasoline at concentrations of 25 ppm, 50 ppm and 100 ppm. The noise and vibration levels of the single-cylinder gasoline engine were then analyzed to determine the effects of these fuel additives.

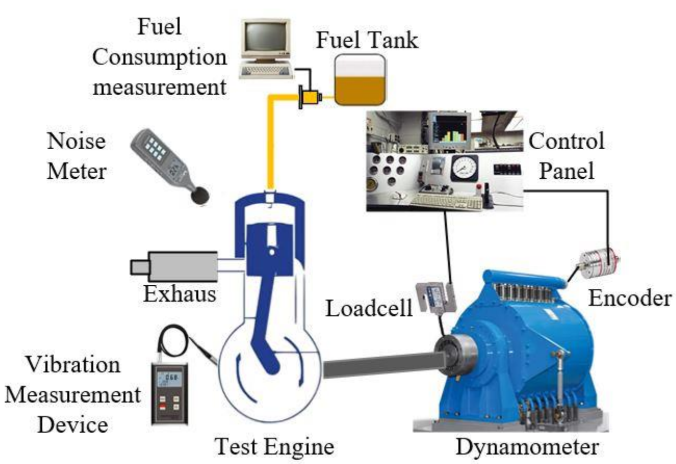

Figure 1. Experimental test setup

2. Materials and Methods

The experiments were performed on a single-cylinder, air-cooled, four-stroke gasoline engine to assess the impact of various fuel mixtures on engine noise and vibration. The engine was operated at a steady speed of 2500 rpm under varying load conditions, ranging from 0% to 100%. An engine dynamometer was employed to accurately control and monitor the engine load throughout the testing process. The experimental setup also incorporated systems for noise measurement and vibration analysis to record essential performance metrics. A schematic representation of the experimental setup is provided in Figure 1.

Noise levels were measured using a calibrated sound level meter positioned 1 meter from the engine. The meter was configured to record in the A-weighted decibel (dBA) scale, which closely reflects the human ear's sensitivity to various frequencies. Measurements were taken at each load level, with data recorded every second and averaged over a 2-minute period. Vibration levels were assessed using a three-axis accelerometer mounted on the engine block. The accelerometer was connected to a data acquisition system, recording vibration in terms of acceleration (m/s^2). Measurements were taken along the X, Y, and Z axes to capture the engine's overall vibration behavior. The vibration data from all three axes were averaged to provide a single overall vibration level for each fuel mixture and load condition. The testing procedure for each fuel mixture was as follows: The engine was pre-warmed for 10 minutes using G fuel to stabilize operating conditions. Throughout the experiment, the engine speed was maintained at a constant 2500 rpm. Fuel mixtures were tested under engine loads of 0%, 25%, 50%, 75%, and 100%. Noise and vibration levels were recorded after a 2-minute stabilization period at each load level. To prevent cross-contamination between fuel mixtures, the engine was run on pure gasoline between tests. Each fuel mixture was tested three times to ensure the repeatability and reliability of the results. Test engine properties are provided in Table 1.

Table 1. Test engine specifications

Brand&Model	Honda GX200
Bore x stroke (mm x mm)	68 x 54
Cylinder volume (cm^3)	196
Number of cylinders	1
Cooling type	Air cooled
Max. power (Hp, @3600 rpm)	6.5
Max. torque (Nm, @2500 rpm)	13.24
Compression ratio	8.5:1

A series of fuel mixtures, detailed in Table 2, range from G, which serves as the baseline fuel, to various blends containing different additive ratios. These blends were carefully prepared in the laboratory using precise volume measurements and thorough mixing to ensure uniform consistency. Initially, benzoylthiourea derivative additives (HL1: $C_{11}H_8ClN_3O_2S$ and HL2: $C_{11}H_8ClN_3OS_2$) were dissolved in 5 mL of DCM at a concentration of 25 ppm, 50 ppm and 100 ppm. The resulting solutions were then added to 1000 mL of G. DCM serves as a versatile solvent for dissolving a wide range of organic compounds in numerous chemical processes. It is produced through two primary methods: the hydrochlorination of methanol and the direct chlorination of methane [33]. The chemical structures of HL1 and HL2 are given in Figure 2 and Figure 3.

Table 2. Test fuel mixtures

Test Fuels	Mixing Ratios
G	100% Gasoline (1000 mL)
G+ DCM	100% Gasoline + 5 mL DCM
G+ DCM + HL1 (25 ppm)	100% Gasoline + 5 mL DCM with HL1 (25 ppm)
G+ DCM + HL2 (25 ppm)	100% Gasoline + 5 mL DCM with HL2 (25 ppm)
G+ DCM + HL1 (50 ppm)	100% Gasoline + 5 mL DCM with HL1 (50 ppm)
G+ DCM + HL2 (50 ppm)	100% Gasoline + 5 mL DCM with HL2 (50 ppm)
G+ DCM + HL1 (100 ppm)	100% Gasoline + 5 mL DCM with HL1 (100 ppm)
G+ DCM + HL2 (100 ppm)	100% Gasoline + 5 mL DCM with HL2 (100 ppm)

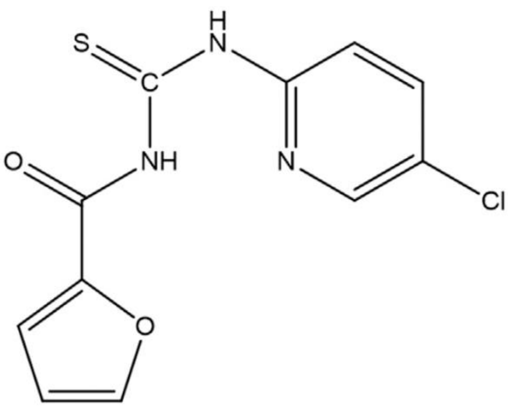

Figure 2. Chemical structure of N-((5-chloropyridin-2-yl)carbamothioyl)furan-2-carboxamide (HL1) [31]

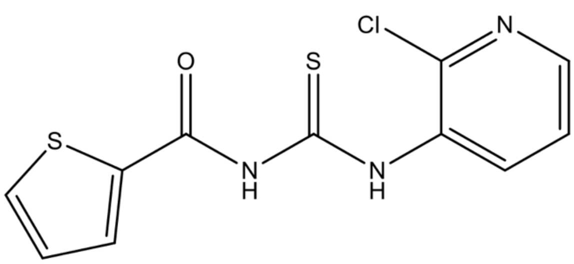

Figure 3. Chemical structure of N-((2-chloropyridin-3-yl)carbamothioyl) thiophene-2-carboxamide (HL2) [32]

Table 3 provides an overview of the fuel properties of gasoline and DCM, including parameters such as density, lower heating value (LHV), viscosity, and other key characteristics essential for evaluating engine performance and emissions. These properties are crucial for analyzing overall fuel efficiency and effectiveness.

Noise and vibration data were processed and analyzed to evaluate the impact of each fuel blend under varying load conditions. The average noise levels (measured in dBA) and vibration levels (measured in m/s²) for each blend were calculated and compared to those of pure gasoline. Full-load conditions were particularly emphasized as they provided the most pronounced insights into each blend's performance in reducing or amplifying noise and vibration. Statistical analyses were conducted to identify significant differences among the fuel blends. Uncertainties and ranges for measurement devices are presented in Table 4.

Table 3. Physicochemical properties of the test fuels [33-35]

Properties	Gasoline	DCM
Chemical Formula	$C_{6-12}H_{14-26}$	CH_2Cl_2
Energy Content-LHV (MJ/kg)	43.594	13
Flash Point (°C)	-43	-
Boiling Point (°C)	27-225	40
Freezing Point (°C)	-52	-95
Density (kg/m3)	746	1330
Viscosity (mPa.s)	0.4-0.8	0.413
Autoignition Temperature (°C)	257	605

Table 4. Uncertainties and ranges for the measurement devices

Measurement	Instrument	Accuracy	Uncertainty (%)
Fuel Consumption	Precision Scale (0.1 g)	±0.1 g	±1%
Exhaust Emissions	Bilsa Emission	CO: ±0.1%,	±2%
Exhaust Emissions	Bilsa Emission	CO_2: ±0.1%,	±2%
Exhaust Emissions	Bilsa Emission	NO_x: ±5 ppm	±2%
Exhaust Emissions	Bilsa Emission	HC: ±2 ppm	±2%
Noise Levels	PCE 322A	±0.1 dBA	±1.5%
Vibration	UNI-T UT315A	±0.01 m/s²	±1%
Engine Load	Dynamometer	±0.01 Nm	±1%
Engine Speed	Tachometer	±10 rpm	±0.5%

3. Results and Discussions

Figure 2 illustrates the noise levels produced by the engine, measured in dBA, for four different fuels and four different engine loads, including the no-load condition. Under the no-load condition, the noise level was measured at 91.24 dBA during engine tests using pure gasoline, whereas it increased to 91.61 dBA when DCM was added to the gasoline. For fuels with HL1 and HL2 additives (25 ppm each) dissolved in DCM and blended with gasoline, the noise levels under no-load conditions were 92.62 dBA and 88.91 dBA, respectively. This represents a 1.51% increase in noise level for the DCM+25 ppm HL1 blended fuel compared to pure gasoline, while the DCM+25 ppm HL2 blended fuel resulted in a 2.55% decrease in noise level.

The noise level measured during the test with pure gasoline at 25% engine load was 92.05 dBA, rising to 98.24 dBA when the engine load increased to 100%. This indicates that pure gasoline generates significant noise, particularly under high-load conditions. Overall, all engine tests demonstrated an increase in noise levels as the engine load increased. This trend highlights a direct relationship between engine load and noise generation, with higher loads resulting in elevated noise levels across all fuel blends.

The DCM-blended fuel mixture resulted in a slight increase in noise levels compared to pure gasoline across all engine loads, including the no-load condition. At full load, the noise level was 5.8% higher than at 25% load. This can be attributed to the slightly lower boiling point of DCM compared to gasoline. Additionally, DCM's higher density relative to gasoline is believed to cause a greater mass of the mixture to enter the cylinder, participating more actively in combustion reactions and intensifying the noise level due to the increased reaction activity.

Engine tests with the DCM + 25 ppm HL1 blended fuel recorded the highest noise levels across all engine loads and the no-load condition compared to all other fuels tested. At 25% load, the noise level reached 93.5 dBA, while at 100% load, it peaked at 99.8 dBA—the highest value observed in all tests. The DCM + 25 ppm HL1 blend appears to significantly increase noise generation, particularly under high-load conditions, likely due to the more volatile nature of the fuel mixture. Conversely, engine tests with the DCM + 25 ppm HL2 blended fuel recorded the lowest noise levels at all engine loads and the no-load condition compared to all fuels tested. At 100% load, the noise level was 95.8 dBA, while at 25% load, it dropped to 88.9 dBA, the lowest value recorded in all tests.

The results indicate that the addition of DCM and DCM + 25 ppm HL1 to gasoline generally increases noise levels. While DCM caused a slight increase, the effect of DCM + 25 ppm HL1 was more pronounced, particularly at higher engine loads. At no load and 25% engine load, the differences in noise levels between the fuel blends were relatively minor, with all fuels producing comparable noise levels. However, as engine load increased, the differences in noise levels became more distinct, highlighting the critical role of fuel composition in noise generation under high-load conditions. The most notable finding from the noise level measurements is that the fuel blend containing DCM + 25 ppm HL2 additive produced significantly lower noise levels across all load conditions compared to pure gasoline. This suggests that the DCM + 25 ppm HL2 blend promotes more stable combustion and slows the reaction rate and activation process. The additive's impact on the calorific value and activation energy of the mixture likely alters the combustion reactions and oxidation rate of the fuel. Consequently, the DCM + 25 ppm HL2 additive is considered a promising option for applications where noise reduction is a critical requirement.

Figure 3 illustrates the variation in engine vibration values for four different fuels and four engine loads, as well as the no-load condition. During the no-load engine test with pure gasoline, the vibration value was measured at 33.4 m/s², which increased to 34.1 m/s² when DCM was added to the gasoline. For fuels with HL1 and HL2 additives (25 ppm each) dissolved in DCM and blended with gasoline, the no-load vibration values were measured at 42.6 m/s² for the DCM + 25 ppm HL1 fuel and 32.5 m/s² for the DCM + 25 ppm HL2 fuel. Compared to pure gasoline, the DCM + 25 ppm HL1 blend increased vibration by 27.54%, while the DCM + 25 ppm HL2 blend reduced vibration by 2.69%.

The vibration values produced by the DCM-blended fuel mixture are slightly higher compared to pure gasoline across all engine loads and in the no-load condition. At full load, the vibration level is 171.85% higher than at 25% load. This increase in vibration can be attributed to the high density, elevated auto-ignition temperature, and low energy content of DCM. The high auto-ignition temperature of DCM likely causes a delay in the combustion process, complicating the combustion conditions by adversely affecting the environment necessary for oxidation reactions within the combustion chamber. Additionally, DCM's higher density compared to gasoline may lead to a greater mass of the mixture being drawn into the cylinder. However, the high density may also reduce DCM's ability to form homogeneous mixtures with gasoline and air, potentially resulting in locally rich mixture zones within the combustion chamber. These localized zones may cause the gas temperature to rise unevenly in certain areas of the chamber, leading to sudden and rapid combustion, which contributes to increased vibration levels. Fuel additives influence the fuel mixture's chemical composition and alter the combustion process's thermodynamic conditions, further impacting engine performance and vibration characteristics.

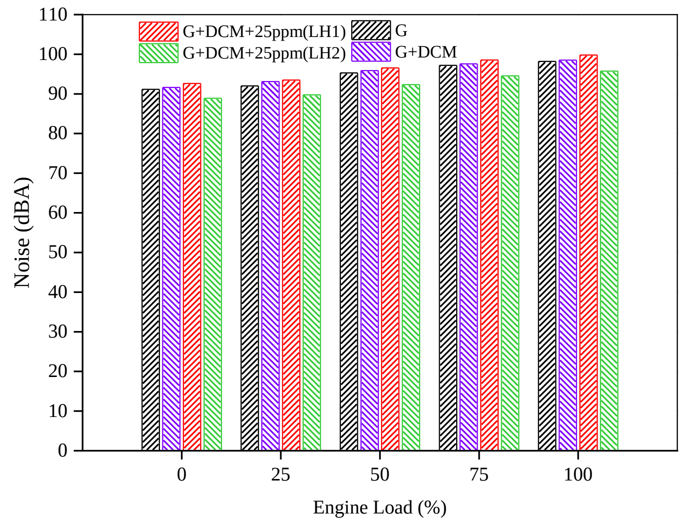

Figure 2. Variation of noise for various test fuels at different load conditions (25 ppm additive)

Engine tests using the DCM + 25 ppm HL1 blended fuel recorded the highest vibration values across all engine loads and in the no-load condition compared to all other fuels tested. At 25% load, the vibration level reached 47.2 m/s², increasing to 94.5 m/s² at 100% load, the highest value observed in all tests. The presence of the DCM + 25 ppm HL1 additive appears to affect the combustion process, leading to rapid combustion reactions. This suggests that the engine operates less stably with this blend than with pure gasoline. It is also anticipated that pressure fluctuations in the combustion chamber increase with this fuel additive during the combustion process, contributing to elevated vibration levels in the engine. In contrast, engine tests using the DCM + 25 ppm HL2 blended fuel measured the lowest vibration levels across all engine loads and in the no-load condition compared to all other fuels tested. At 100% load, the vibration level was 80.5 m/s², decreasing to 32.5 m/s² at 25% load, the lowest value recorded in all tests. The DCM + 25 ppm HL2 additive is believed to promote more uniform and stable combustion. As the flame front progresses more smoothly and combustion remains consistent, vibration levels are thought to be reduced.

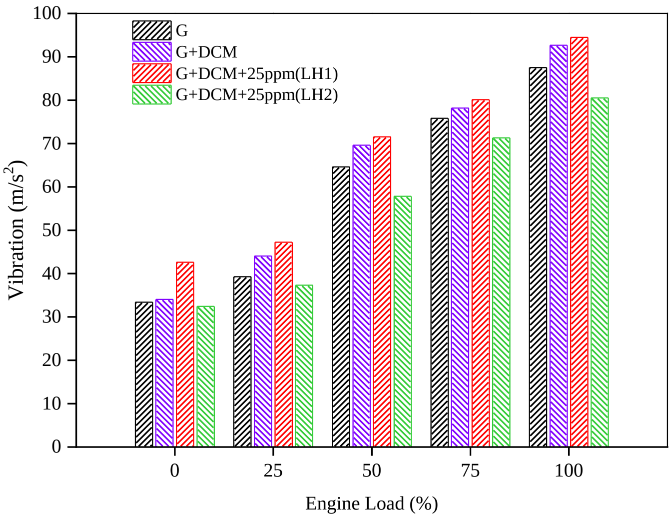

Figure 3. Variation of vibration for various test fuels at different load conditions (25 ppm additive)

The noise levels for different fuel blends and engine loads are summarized in Figure 4. Based on the experimental results, noise levels increased with engine load for all fuel blends, reflecting the higher combustion pressures and mechanical stresses at higher loads. At 0% engine load, the lowest noise level was observed with pure gasoline at 91.15 dBA. The closest result to gasoline was recorded with LH2, which showed a slight increase of 0.23%, producing a noise level of 91.36 dBA. The highest noise level at 0% load was observed with LH1, reaching 95.31 dBA, which represented a 4.56% increase compared to gasoline. At 25% engine load, the noise level for gasoline was measured at 92.01 dBA. The addition of LH1 resulted in the highest noise level at this load, reaching 96.26 dBA. On the other hand, LH2 produced a noise level of 93.09 dBA, which was closer to the value for gasoline. At 50% engine load, the lowest noise level was achieved with LH2, producing a value of 94.21 dBA, which represented a 1.15% reduction compared to gasoline. In contrast, the highest noise level at this load was recorded with LH1 at 97.98 dBA. At 75% engine load, LH1 again resulted in the highest noise level, measuring 99.48 dBA. In comparison, LH2 produced the lowest noise level at 96.75 dBA. At 100% engine load, LH2 provided the lowest noise level of 96.69 dBA, which was a 1.51% reduction compared to gasoline at 98.18 dBA. The highest noise level at full load was recorded with LH1 at 99.35 dBA. Adding DCM to gasoline generally increased noise levels compared to pure gasoline. This increase can be attributed to the effects of DCM on combustion characteristics, such as increased knocking tendencies and changes in flame propagation. Combining DCM with LH1 further amplified noise levels, producing the highest values across all engine loads. This may be due to the impact of LH1 on octane rating and combustion intensity. Conversely, adding LH2 reduced noise levels, particularly at 50% and above engine loads, where it consistently provided the lowest noise levels. This reduction can likely be attributed to LH2's superior knock resistance and stabilizing effects on combustion. LH2 demonstrated its effectiveness in maintaining or reducing noise levels compared to gasoline, particularly under high-load conditions. This makes LH2 a promising additive for quieter engine operation. On the other hand, LH1's tendency to increase noise levels may limit its suitability for applications requiring low-noise operation. In summary, noise levels increased with engine load for all fuel blends. Adding DCM and LH1 contributed to higher noise levels, with LH1 causing the largest increases. In contrast, LH2 consistently reduced noise levels, particularly for 50% and above engine loads. At 100% load, LH2 achieved a 1.51% reduction in noise compared to gasoline. These findings highlight LH2's potential to improve engine noise characteristics, particularly under higher load conditions, while LH1 may require further optimization to reduce its noise-increasing effects.

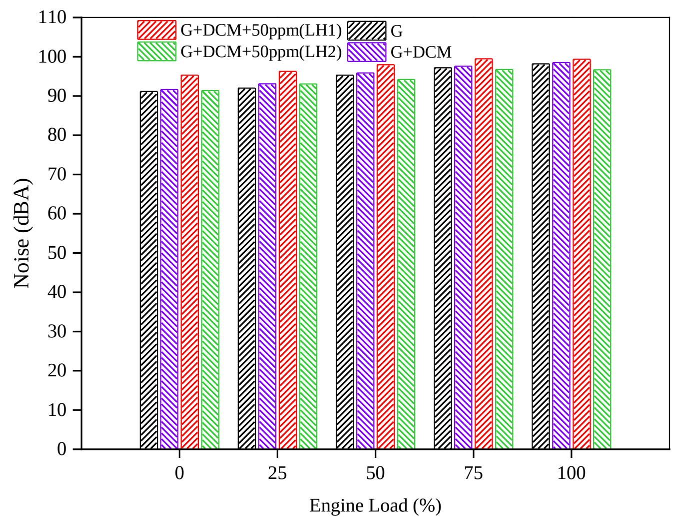

Figure 4. Variation of noise for various test fuels at different load conditions (50 ppm additive)

The vibration values of 50 ppm additives for different engine loads and fuel blends are presented in Figure 5. As engine load increased, vibration levels generally increased for all fuel blends. This trend aligns with the expected behavior due to the higher mechanical and combustion stresses at higher loads.

The lowest vibration level (33.4 m/s²) was observed at no-load conditions with gasoline. The closest result was obtained with a 50 ppm addition of LH2 (33.78 m/s²), showing only a 1.14% increase compared to gasoline. The highest vibration level (38.3 m/s²) was recorded with LH1, resulting in a 14.67% increase compared to gasoline. Gasoline again exhibited the lowest vibration (39.29 m/s²), while the highest vibration (53.95 m/s²) was recorded with LH1 at 25% engine load. LH1 caused a 37.32% increase compared to gasoline. At 50% load, The lowest vibration (48.68 m/s²) was observed with LH2, while the highest vibration (71.93 m/s²) was recorded with LH1. LH2 achieved a 24.64% improvement, whereas LH1 caused an 11.34% deterioration compared to gasoline. The lowest vibration level (83.63 m/s²) was achieved with LH2, while the highest vibration (94.25 m/s²) occurred with LH1 at full load. The addition of DCM led to a general increase in vibration levels compared to gasoline due to its density and viscosity, which may influence combustion dynamics and increase the risk of knocking. 50 ppm LH1 further amplified vibration levels, particularly at lower engine loads, likely due to its effects on octane rating and combustion characteristics. Conversely, LH2 demonstrated significant vibration reductions at 50% and above engine loads. This reduction is likely due to LH2's high knock resistance and its stabilizing effect on combustion. The combination of DCM+50 ppm LH2 consistently resulted in reduced vibration levels at higher engine loads, making it a promising additive for mitigating engine vibrations in heavy-duty applications. The use of LH1, while beneficial for certain performance parameters, may require optimization to prevent excessive vibrations, particularly at lower engine loads. LH2 shows potential for improving engine stability and reducing vibrations, especially in scenarios requiring high-load operation. DCM alone increases vibration levels due to its physical properties affecting combustion. DCM+50 ppm LH1 exacerbates vibrations, particularly at low loads, due to its influence on octane and combustion dynamics. DCM+ 50 ppm LH2 demonstrates the ability to reduce vibrations at higher loads, likely due to its superior knock resistance.

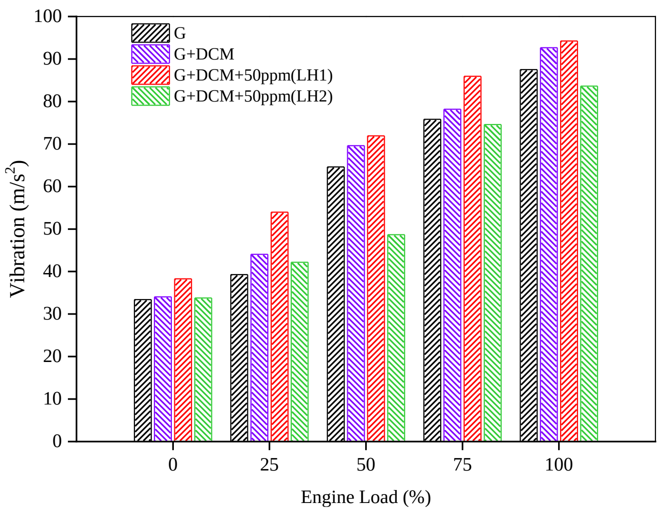

Figure 5. Variation of vibration for various test fuels at different load conditions (50 ppm additive)

The results for noise levels across different fuel blends and engine loads are shown in Figure 6. The measurements at loads ranging from 0% to 100% indicate noticeable variations among the fuel mixtures. Noise levels of G ranged from 91.15 dBA at 0% load to 98.18 dBA at 100% load. A gradual increase in noise levels is observed with the increasing engine load, consistent with expectations due to higher combustion pressures and mechanical stresses. Noise levels of G+DCM were slightly higher than the baseline, ranging from 91.64 dBA at 0% load to 98.52 dBA at 100% load. The inclusion of DCM resulted in a marginal increase in noise, likely due to its lower energy content and differing combustion characteristics compared to pure gasoline. Adding 100 ppm, LH1 led to noise levels slightly higher than G+DCM, ranging from 91.83 dBA at 0% load to 100.99 dBA at 100% load. The increase in noise could be attributed to the chemical properties of LH1, which may alter the combustion process and result in increased acoustic emissions. LH2 showed the highest noise levels among all mixtures, ranging from 92.03 dBA at 0% load to 99.19 dBA at 100% load. The higher noise levels may indicate that LH2 affects the combustion process differently than HL1, possibly leading to more intense pressure fluctuations within the engine cylinder. For all fuel blends, noise levels increased with engine load, reflecting the impact of higher thermal and mechanical loads on noise generation. The rate of noise increase appeared more pronounced for LH1 and LH2 blends compared to the baseline and DCM blends, suggesting that the additives amplify noise at higher loads. While DCM alone had a negligible effect on noise levels, the combination of DCM with LH1 and LH2 caused noticeable increases in noise, particularly under full-load conditions. LH2 consistently produced higher noise levels than HL1 at all load conditions, suggesting that its combustion characteristics may differ significantly. Overall, while the 100 ppm addition of LH1 and LH2 resulted in increased noise levels, particularly at higher engine loads, these changes need to be weighed against potential fuel efficiency and emissions benefits.

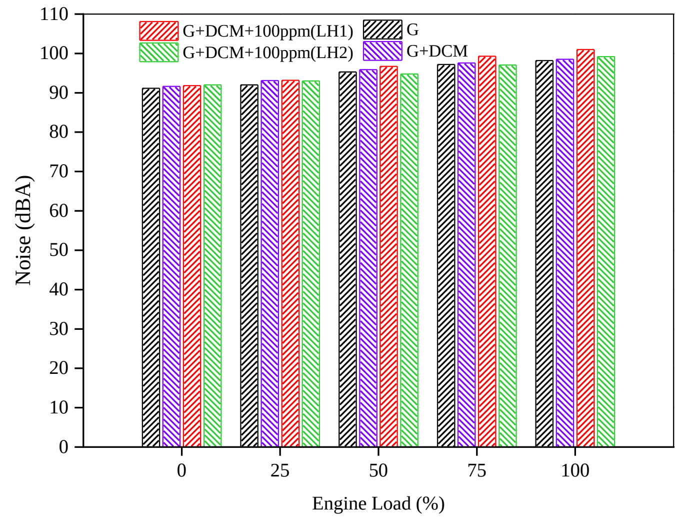

Figure 6. Variation of noise for various test fuels at different load conditions (100 ppm additive)

The vibration levels for the different fuel mixtures and engine loads are shown in Figure 7. Measurements, expressed in terms of acceleration (m/s²), were recorded at loads ranging from 0% to 100%. Vibration levels increased from 33.40 m/s² at 0% load to 87.50 m/s² at 100% load for Gasoline. The steady increase in vibration with engine load reflects typical engine behavior, where higher loads induce greater mechanical forces and dynamic imbalances. Vibration levels for G+DCM were slightly higher than the baseline, ranging from 34.05 m/s² at 0% load to 92.67 m/s² at 100% load. The addition of DCM marginally altered the engine's combustion characteristics, leading to slightly higher vibrations across all load conditions. The addition of LH1 at 100 ppm resulted in higher vibration levels at lower loads (e.g., 41.2 m/s² at 0%) but comparable levels to G+DCM at full load (87.4 m/s² at 100% load). The sharp increase in vibration at lower loads suggests that LH1 affects combustion stability, potentially introducing uneven forces during operation. LH2 showed distinct behavior, with vibration levels ranging from 39.53 m/s² at 0% load to 85.51 m/s² at 100% load. Notably, LH2 exhibited lower vibration levels than both G and G+DCM at higher loads (e.g., 85.51 m/s² vs. 87.5 m/s² for G at 100% load), indicating a stabilizing effect under high-load conditions. Across all fuel blends, vibration levels increased with engine load due to greater mechanical stresses and dynamic forces. While the additives caused variations in vibration levels, the overall trends were consistent across all blends. LH1 resulted in the highest increase in vibration at lower loads, possibly due to its impact on combustion dynamics. LH2 demonstrated a stabilizing effect at higher loads, reducing vibrations compared to the baseline fuel. DCM increased vibration levels slightly compared to pure gasoline, likely due to its lower energy content and its effect on combustion efficiency. Vibration levels across all fuels showed a predictable increase with load, emphasizing the influence of mechanical stresses and combustion pressure fluctuations. The increased vibration levels at lower loads with LH1 suggest potential issues with combustion stability, which may require further optimization of additive concentration. The lower vibration levels at higher loads with LH2 highlight its potential as a stabilizing agent for engines operating under heavy-duty conditions. Higher vibrations can impact engine durability and user comfort, so balancing additive benefits with potential drawbacks is crucial.

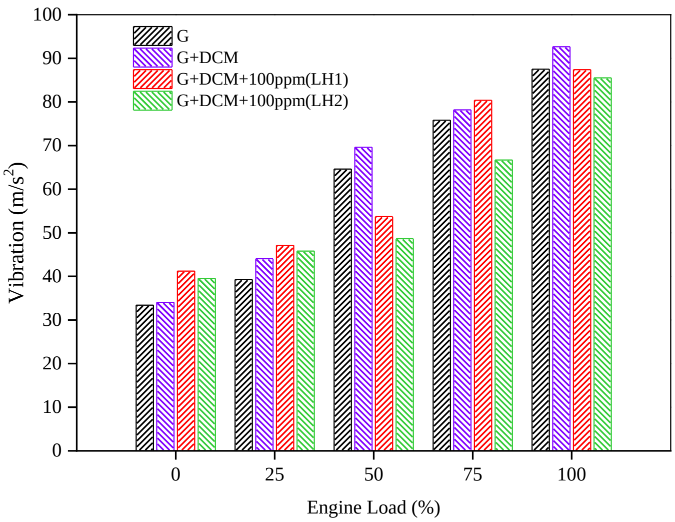

Figure 7. Variation of vibration for various test fuels at different load conditions (100 ppm additive)

4. Conclusions

The experimental results provide a detailed analysis of the effects of DCM and benzoylthiourea derivatives (LH1 and LH2) at concentrations of 25 ppm, 50 ppm, and 100 ppm on engine noise levels. Based on the data provided, key conclusions, including percentage improvements and deteriorations compared to pure gasoline, are as follows:

- Adding DCM to gasoline caused slight increases in noise levels across all engine loads. At no load, the noise increased by 0.53% compared to gasoline, while at 100% load, it increased by 0.34%. These increases are likely due to DCM's lower energy content and higher density, leading to altered combustion dynamics.
- Adding DCM+LH1 25 ppm, Noise levels increased by 1.62% at no load and 1.65% at 100% load compared to gasoline. In addition to DCM+LH1 50 ppm, Noise levels rose by 4.55% at no load and 1.19% at 100% load compared to gasoline. In addition to DCM+LH1, 100 ppm LH1 caused the most significant increases in noise levels. Noise levels increased by 6.77% at no load and 2.87% at 100% load compared to gasoline. The results indicate that LH1 consistently increases noise levels, intensifying the effects at higher concentrations. The volatile nature of LH1 and its impact on combustion dynamics likely contribute to these increases.
- Adding DCM+LH2 25 ppm noise levels decreased by 2.77% at no-load and 2.47% at 100% load compared to gasoline. At DCM + LH2 50 ppm, LH2 continued to reduce noise but with slightly less impact. Noise levels decreased by 0.21% at no-load and 1.51% at 100% load compared to gasoline. At 100 ppm, HL2 provided the best performance: Noise levels decreased by 0.78% at no load and 1.98% at 100% load compared to gasoline. These results highlight that HL2 is an effective additive for reducing noise levels, particularly at 25 ppm and 100 ppm concentrations. Its high knock resistance and ability to stabilize combustion contribute to its noise-reducing effects.
- DCM alone causes slight increases in noise levels and has minimal effect compared to LH1 additives. LH1 consistently increases noise levels, making it less desirable for noise-sensitive applications. Its effects worsen at higher concentrations, suggesting a need for optimization. LH2, particularly at 25 ppm and 50 ppm, significantly reduces noise levels compared to gasoline at high loads, making it the most promising additive for reducing engine noise.

The impact of benzoylthiourea additives on engine noise and vibration remains under investigation. Analyzing the effects of these additives on gasoline and diesel engines, particularly at varying concentrations, could provide valuable contributions to the existing body of literature.

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Nomenclature

IC	Internal Combustion
SI	Spark Ignition
DCM	Dichloromethane
dBA	Decibel
LHV	Lower Heating Value
BSFC	Brake Specific Fuel Consumption

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Sertaç Coşman: Conceptualization, Supervision, Writing-original draft, Software **Samet Çelebi:** Conceptualization, Supervision, Writing-original draft, Writing - review & editing, Methodology

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