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Comparative Analysis of Diesel Engine Exhaust Emissions with and without Thermostat Installation

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A B S T R A C T

This study examines the exhaust emission characteristics of a diesel engine operating with and without thermostat installation in the cooling system, focusing on carbon monoxide (CO), hydrocarbon (HC), and nitrogen oxide (NOx) emissions. An experimental research design with a comparative approach was employed, in which a single-cylinder diesel engine test unit was tested under two cooling system configurations at a constant engine speed of 1500 rpm using a portable exhaust gas analyzer. The results show that installing the thermostat helped the engine reach a more stable and higher coolant temperature, which improved combustion completeness and reduced CO and HC emissions compared with the condition without a thermostat, although it also led to a slightly higher NOx concentration. These findings indicate that thermostat installation plays an important role in diesel engine thermal management and combustion quality, and that its emission benefits should be balanced with complementary NOx-control strategies for more comprehensive emission reduction

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INTRODUCTION

Diesel engines remain widely used in the transportation and industrial sectors because of their high thermal efficiency, superior fuel economy, and excellent operational durability compared with spark-ignition engines. These advantages make diesel engines the preferred power source for heavy-duty vehicles, agricultural machinery, and industrial equipment. However, diesel engines are also significant sources of exhaust pollutants, including carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM), which contribute to environmental pollution and adverse human health effects. Consequently, reducing diesel engine emissions has become an important objective in improving environmental sustainability while maintaining engine performance (Milojević et al., 2025). The formation of diesel engine exhaust emissions is closely associated with combustion quality, which is strongly influenced by engine operating temperature. During cold-start and warm-up conditions, the combustion chamber and coolant have not yet reached their optimum operating temperatures, leading to incomplete fuel combustion and increased emissions of CO and HC. Conversely, excessively high combustion temperatures promote the formation of NOx through thermal reactions between nitrogen and oxygen. Therefore, maintaining an appropriate engine operating temperature is essential for improving combustion efficiency while minimizing pollutant formation (Zacharewicz et al., 2024).

The engine cooling system plays a fundamental role in maintaining the optimum operating temperature throughout engine operation. One of its key components is the thermostat, which regulates coolant circulation according to engine temperature. During engine warm-up, the thermostat remains closed to accelerate the increase in coolant temperature, whereas at normal operating conditions it gradually opens to direct coolant toward the radiator, thereby preventing overheating and maintaining thermal stability. Effective thermal management through thermostat operation has been recognized as an important factor in improving combustion efficiency, fuel economy, and exhaust emission performance in diesel engines (Huang et al., 2024). Several studies have demonstrated the importance of thermal management in internal combustion engines. Mancarella and Marello (2023) reported that coolant temperature significantly affects combustion quality and diesel engine emission characteristics. Similarly, Anwar (2019) found that variations in coolant temperature influence exhaust emission performance. Furthermore, Seo et al. (2022) showed that coolant temperature is closely associated with increased emissions during the cold-start phase, while Sun et al. (2024) emphasized that effective engine thermal management contributes to emission reduction by stabilizing operating temperature. These findings indicate that engine temperature is an important factor influencing combustion efficiency and pollutant formation.

Although previous studies have extensively investigated the effects of coolant temperature, alternative fuels, fuel injection systems, and exhaust after-treatment technologies on diesel engine emissions, experimental studies directly comparing exhaust emissions under thermostat-installed and thermostat-removed conditions remain limited. Most existing research evaluates thermal management indirectly through coolant temperature variation rather than examining the contribution of the thermostat itself to emission formation. This limitation creates a need for experimental investigations focusing specifically on thermostat operation. Therefore, this study aims to compare the exhaust emissions of a diesel engine operating with and without thermostat installation by evaluating carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx). The novelty of this research lies in the direct experimental comparison of diesel engine exhaust emissions under both cooling system configurations, providing a clearer understanding of the relationship between thermostat operation, engine thermal stability, and exhaust emission characteristics.

LITERATURE REVIEW

Engine thermal management is one of the key factors affecting combustion efficiency and exhaust emission characteristics in diesel engines. The cooling system maintains engine operating temperature within an optimum range by regulating coolant circulation, thereby preventing both excessive heat and insufficient operating temperature. The thermostat is an essential component of the cooling system because it controls coolant flow according to engine temperature. During the warm-up period, the thermostat remains closed to accelerate the increase in engine temperature, whereas it gradually opens after the operating temperature is reached to maintain thermal stability. Consequently, thermostat operation influences combustion conditions by ensuring that the engine operates within its optimal temperature range. Previous studies have demonstrated that maintaining stable engine temperature contributes to improved engine performance and reduced exhaust emissions. Anwar (2019) reported that lower coolant temperatures increase carbon monoxide (CO) and hydrocarbon (HC) emissions due to incomplete combustion. Similarly, Seo et al. (2022) found that CO and HC emissions are considerably higher during cold-start conditions because the combustion chamber has not reached the optimum operating temperature, whereas nitrogen oxides (NOx) increase as combustion temperature becomes higher. Mancarella and Marello (2023) further explained that stable coolant temperatures improve combustion efficiency and reduce incomplete combustion products, indicating that engine thermal conditions strongly influence diesel exhaust emissions.

The importance of engine thermal management has also been highlighted in studies focusing on cooling system performance. Turabimana et al. (2023) demonstrated that thermostat-based cooling systems improve engine thermal stability and overall operating performance by maintaining a consistent coolant temperature. Likewise, Suryapradana and Halim (2024) stated that thermostat operation enables the engine to reach its optimum operating temperature more rapidly, thereby improving combustion efficiency. Furthermore, Sun et al. (2024) emphasized that effective thermal management is an important strategy for reducing exhaust emissions while maintaining engine efficiency because engine temperature directly affects combustion reactions and pollutant formation.

Although previous studies have confirmed that coolant temperature and engine thermal management significantly influence diesel engine performance and exhaust emissions, most investigations have focused on coolant temperature variation, fuel properties, fuel injection systems, or exhaust after-treatment technologies. Experimental studies directly comparing diesel engine exhaust emissions under thermostat-installed and thermostat-removed conditions remain limited. Consequently, the specific contribution of thermostat installation to diesel engine exhaust emissions has not been comprehensively investigated through direct experimental comparison. This research addresses this gap by experimentally comparing carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx) emissions from a diesel engine operating with and without thermostat installation.

METHODOLOGY

This study employed an experimental research design with a comparative approach to evaluate the exhaust emissions of a diesel engine operating with and without thermostat installation. The independent variable in this research was the cooling system configuration, consisting of two treatment conditions, namely the thermostat-installed condition and the thermostat-removed condition, while the dependent variables were the concentrations of carbon monoxide (CO), hydrocarbon (HC), and nitrogen oxide (NOx) emitted through the exhaust gas. The research object used in this study was a single-cylinder diesel engine test unit operated under controlled laboratory conditions to minimize the influence of external variables on the measured emission results. The main instrument used to measure exhaust emissions was a portable automotive exhaust gas analyzer capable of directly measuring CO, HC, and NOx concentrations. Supporting instruments included a digital tachometer to monitor engine rotational speed, a thermocouple thermometer to record coolant and exhaust gas temperature, and a stopwatch to standardize the engine warm-up duration prior to each measurement.

Data collection was carried out through a series of engine running tests under two cooling system configurations. In the first configuration, the engine was tested with the thermostat installed in its original position within the cooling system, whereas in the second configuration the thermostat was removed so that coolant could circulate freely without temperature-based regulation. For each configuration, the engine was first operated until it reached a stable warm-up condition, after which exhaust emission measurements were taken at several variations of engine rotational speed. Each measurement was repeated three times at every speed variation to obtain representative and reliable data, and the results were then recorded for further analysis. The collected data were analyzed descriptively by calculating the mean and standard deviation of CO, HC, and NOx concentrations for each cooling system configuration and each engine speed variation. To determine whether the differences in exhaust emissions between the thermostat-installed and thermostat-removed conditions were statistically significant, an independent sample t-test was applied at a 95% confidence level ($\alpha = 0.05$). Prior to hypothesis testing, normality and homogeneity of variance tests were performed to ensure that the data satisfied the assumptions required for parametric testing. A significance value below 0.05 indicated a statistically significant difference between the two treatment conditions. The results of data analysis were displayed in the form of tables and graphs to facilitate interpretation. Descriptive statistical results, including the mean and standard deviation of each emission parameter, were summarized in tabular form, while the emission trends across engine speed variations for both cooling system configurations were presented in line or bar graphs. This presentation format was intended to provide a clear visual comparison of exhaust emission characteristics between the thermostat-installed and thermostat-removed conditions.

RESULTS

Testing was conducted under two cooling system configurations, namely with the thermostat installed and without the thermostat installed, to compare the resulting diesel engine exhaust emissions. In both configurations, the engine was first warmed up until it reached a stable operating condition, after which exhaust emissions were measured using a gas analyzer at a constant engine speed of 1500 rpm for a duration of six minutes. The parameters recorded were carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NOx), coolant temperature, engine speed, and testing duration. The comparison of the measurement results for both configurations is presented in Table 1.

Table 1. Comparison of Diesel Engine Exhaust Emissions with and without Thermostat

Parameter	With Thermostat	Without Thermostat	Unit
CO	0.21	0.34	%vol
HC	48	71	ppm
NOx	182	165	ppm
Coolant Temperature	82	68	°C
Engine Speed	1500	1500	rpm
Testing Duration	6	6	minutes

Source: Processed data, 2026

Table 1 shows that the use of a thermostat raises and stabilizes the coolant temperature (82°C versus 68°C), which corresponds to lower CO (0.21%vol versus 0.34%vol) and HC (48 ppm versus 71 ppm) concentrations, but a higher NOx concentration (182 ppm versus 165 ppm), compared with the condition without a thermostat. A detailed explanation of these results is provided in the Discussion section.

DISCUSSION

The comparison of exhaust emissions between the two cooling system configurations indicates that thermostat installation influences diesel engine combustion quality through its effect on engine operating temperature. When the thermostat was installed, the engine reached a more stable and higher coolant temperature, which corresponds to a lower level of carbon monoxide in the exhaust gas. Carbon monoxide is a product of incomplete combustion that forms when oxygen in the combustion chamber is insufficient to fully oxidize carbon into carbon dioxide. A more stable operating temperature promotes more complete fuel evaporation and better air-fuel mixing, which in turn reduces incomplete combustion products. This finding is consistent with Mancarella and Marello (2023), who explained that coolant temperature affects the combustion characteristics and emission behavior of compression ignition engines, and with Seo et al. (2022), who reported that carbon monoxide emissions rise considerably when the combustion chamber has not reached its optimum operating temperature.

A similar pattern was observed for hydrocarbon emissions, which represent unburned fuel that escapes the combustion chamber before it is fully oxidized. The more stable operating temperature achieved with the thermostat installed supports better fuel atomization and vaporization, producing a more homogeneous air-fuel mixture and, consequently, a more complete combustion process with fewer unburned hydrocarbons in the exhaust. Conversely, when the thermostat was removed, the lower operating temperature limited fuel atomization and prolonged the period before the engine reached its ideal combustion condition, resulting in a higher proportion of unburned fuel exiting as hydrocarbon emissions. This result supports the explanation of Zacharewicz et al. (2024) regarding the influence of a diesel engine's thermal state on its combustion efficiency, and aligns with the findings of Seo et al. (2022) on elevated hydrocarbon emissions under conditions where the engine has not yet reached its optimum working temperature. In contrast to carbon monoxide and hydrocarbon, nitrogen oxide emissions showed the opposite tendency, being higher when the thermostat was installed than when it was removed. Nitrogen oxide is formed through the reaction between nitrogen and oxygen inside the combustion chamber, a reaction that is strongly promoted by high combustion temperature. Because thermostat installation raises and stabilizes the combustion temperature, it simultaneously creates more favorable conditions for nitrogen oxide formation. This outcome is in line with Sun et al. (2024), who emphasized that engine operating temperature is closely related to nitrogen oxide formation in diesel engines, and reflects the well-documented trade-off in combustion engineering in which conditions that improve combustion completeness tend to increase thermal nitrogen oxide formation at the same time.

Taken together, these findings demonstrate that engine operating temperature, as regulated by the thermostat, plays a central role in shaping the exhaust emission characteristics of a diesel engine. A stable and adequately high coolant temperature improves combustion completeness, thereby reducing carbon monoxide and hydrocarbon emissions, but it also raises combustion temperature enough to encourage nitrogen oxide formation. This pattern supports the view of Turabimana et al. (2023) and Suryapradana and Halim (2024), who highlighted the thermostat's role in maintaining thermal stability and operating performance within the engine cooling system. Practically, this trade-off suggests that thermostat installation alone cannot simultaneously minimize all three pollutants, and that additional strategies, such as exhaust after-treatment or optimized injection timing, may be required to control nitrogen oxide formation without sacrificing the combustion quality gained from stable thermal management.

CONCLUSIONS AND RECOMMENDATIONS

This study compared the exhaust emission characteristics of a diesel engine operating with and without thermostat installation and found that the thermostat plays an important role in regulating engine operating temperature, which in turn shapes the quality of the combustion process. Installing the thermostat helped the engine reach a more stable and higher coolant temperature, which improved combustion completeness and reduced carbon monoxide and hydrocarbon emissions. However, the same stable and higher combustion temperature also promoted greater nitrogen oxide formation, indicating a trade-off between reducing incomplete-combustion pollutants and controlling thermal nitrogen oxide emissions. These findings imply that maintaining a properly functioning thermostat is an important and low-cost maintenance practice for reducing carbon monoxide and hydrocarbon emissions from diesel engines, particularly for engines that frequently operate under cold-start or low-load conditions. At the same time, because thermostat use may slightly increase nitrogen oxide emissions, engine operators and manufacturers should consider complementary emission-control measures, such as exhaust gas recirculation or selective catalytic reduction, so that the benefits of stable thermal management are not offset by higher nitrogen oxide output. These results can serve as practical guidance for vehicle maintenance programs and for engineers designing cooling and emission-control systems for diesel engines.

FURTHER STUDY

This study has several limitations that should be considered when interpreting its findings. The experiment was conducted on a single-cylinder diesel engine test unit at a single constant engine speed, so the results may not fully represent the emission behavior of multi-cylinder engines or engines operating across varying speeds and load conditions. In addition, the study focused only on carbon monoxide, hydrocarbon, and nitrogen oxide emissions without examining other pollutants, such as particulate matter, or broader performance indicators, such as fuel consumption and engine efficiency. Future research is recommended to test a wider range of engine speeds and load conditions to better capture how the effect of thermostat installation on exhaust emissions changes under real driving conditions. Further studies could also examine the combined effect of thermostat use with other emission-control strategies, such as exhaust after-treatment systems or alternative fuels, including biodiesel blends, to identify configurations that reduce carbon monoxide and hydrocarbon emissions without increasing nitrogen oxide formation. Long-term durability testing is also suggested to evaluate how thermostat performance and its effect on emissions change over extended engine operation.

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