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Comparison of Fuel Consumption in the C223 Diesel Engine with and Without a Thermostat: Analysis of Operating Conditions with the Most Significant Differences

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A B S T R A C T

This study aims to determine the effect of thermostat use on the fuel consumption of the C223 diesel engine, as well as the operating conditions that result in the most significant difference in fuel consumption between engines with and without a thermostat. The study was motivated by the overcooling that occurs when the thermostat is removed, causing the engine to operate below its optimal operating temperature, which leads to incomplete combustion and increased fuel consumption. The method used was a quantitative experiment with a two-group comparison quasi-experimental design, utilizing a single C223 diesel engine tested at 1,500 rpm for 10 minutes with three replicates for each condition: with a thermostat (WT) and without a thermostat (WOT). The results showed that the average fuel consumption for the WT condition was 197.67 ml (1.19 liters/hour), which was lower than that for the WOT condition at 217.67 ml (1.31 liters/hour), representing a difference of 10.12%

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INTRODUCTION

Diesel engines remain one of the primary power sources in various sectors—such as transportation, agriculture, small-scale industry, and power generation—due to their high thermal efficiency, high torque at low RPM, and excellent operational reliability (Nagappan & Babu, 2024). Diesel engine performance is generally evaluated using parameters such as brake-specific fuel consumption (BSFC), brake thermal efficiency (BTE), and exhaust emissions (Nagappan & Babu, 2024). In addition to the influence of fuel type, thermal conditions and engine thermal management also play a significant role in determining the system's overall efficiency (NeuroQuantology, 2022). Thermal analysis of diesel engines shows that fuel energy lost as heat through the cooling system and exhaust gases can reach 35–40%, so reducing heat loss has the potential to lower fuel consumption (NeuroQuantology, 2022).

A thermostat is a temperature control component in a cooling system that regulates coolant flow based on temperature, allowing the engine to reach and maintain an operating temperature within the ideal range (Suryapradana & Halim, 2024). When the thermostat is removed, the engine may operate under overcooling conditions that is, with an operating temperature below the optimal range resulting in incomplete combustion and increased fuel consumption. It is important to understand this phenomenon not only in terms of whether or not the thermostat has an effect, but also in terms of under what operating conditions that effect is most pronounced, given that the engine's heat transfer characteristics vary at different RPM levels and under different loads. Based on this discussion, the research question addressed in this article is formulated as follows: Under what operating conditions is the difference in fuel consumption between the C223 diesel engine with a thermostat and without a thermostat most significant?

Empirical evidence regarding the impact of thermostat release on fuel consumption has been demonstrated through several experimental studies. Amni et al. conducted tests on a Toyota Kijang 5K engine at various engine speeds (800, 1100, 1400, 1700, and 2000 rpm) and found that releasing the thermostat increased fuel consumption by 10.05%, with significant t-test results across all speed variations (Amni et al., 2014). Albert K. Arkoh et al. , in a comparative study of a Ford VSG 413 gasoline engine operated at a constant 1,500 rpm, reported that an engine without a thermostat consumed significantly more fuel and produced higher levels of CO emissions and explosive gases compared to an engine with a thermostat (Albert K. Arkoh et al., 2021). Suryapradana & Halim analyzed the application of a thermostat in the cooling system of a Nissan CWB 45 dump truck with a target coolant temperature of 80–90°C, and found that at 560, 1000, and 1500 rpm for 15 minutes, the coolant temperatures reached (54.1°C; 61.7°C; 67.7°C) remained below the thermostat's full-activation temperature, and that engine speed affects the rate of coolant temperature rise (Suryapradana & Halim, 2024). Abdullah demonstrated that changes in fuel thermal conditions have a significant impact on brake power, torque, fuel consumption, and the thermal efficiency of diesel engines (Abdullah, 2021).

These previous studies have demonstrated that disabling the thermostat increases fuel consumption and that engine speed affects the rate at which operating temperature is reached. However, studies that explicitly compare fuel consumption between two identical cooling system configurations differing only in the presence of a thermostat while also identifying under which operating conditions (combinations of RPM and load) these differences are most pronounced in the C223 diesel engine remain very limited. This gap underscores the need for further analysis of the operating conditions that are most sensitive to the presence of a thermostat in the C223 diesel engine. In line with the research problem formulated, the objective of this study is to identify and analyze the operating conditions under which the difference in fuel consumption between the C223 diesel engine with and without a thermostat is most significant.

LITERATURE REVIEW

A diesel engine is a type of internal combustion engine that operates on the principle of compressing air to high pressure and temperature, thereby causing the injected fuel to undergo self-ignition (Abdullah, 2021). In a four-stroke diesel engine, the operating cycle consists of the intake, compression, power, and exhaust strokes, which are completed in two crankshaft revolutions (Nagappan & Babu, 2024). Effective combustion depends heavily on the quality of the fuel-air mixture, compression conditions, and combustion chamber temperature (Nagappan & Babu, 2024).

The engine cooling system serves to maintain the engine's operating temperature within a specific range so that combustion proceeds optimally and components do not experience excessive wear or thermal damage (Suryapradana & Halim, 2024). A diesel engine cooling system generally consists of a water jacket in the cylinder block and head, a water pump, a radiator, a fan, connecting pipes, and flow control components such as a thermostat (Suryapradana & Halim, 2024). Thermal analysis of low-heat-rejection diesel engines shows that the proportion of fuel energy lost as heat through the cooling system and exhaust gases can reach 35–40%, so reducing heat loss has the potential to improve thermal efficiency (NeuroQuantology, 2022).

A thermostat is a temperature control component installed in the coolant circuit between the engine and the radiator to regulate coolant flow based on temperature (Suryapradana & Halim, 2024). At low temperatures, the thermostat closes or restricts the flow of coolant to the radiator so that the engine can reach operating temperature more quickly; when the coolant temperature reaches the set point, the thermostat begins to open and regulates the flow of coolant to the radiator (Suryapradana & Halim, 2024)ya. A similar principle is also applied in other thermal systems: (Tusiime et al., 2023) demonstrate that mechanical thermostats in oil-based thermal energy storage systems are capable of maintaining the energy charging temperature close to the set point, while (Simamora & Siringo- ringo, 2023) explain that thermostats whether mechanical or electronic operate by detecting temperature changes and opening and closing the flow to keep the system temperature around the desired value.

Fuel consumption in an engine is often expressed as brake-specific fuel consumption (BSFC), which is the mass of fuel required to produce one unit of power output per unit of time (Nagappan & Babu, 2024). The lower the BSFC value, the more efficient the engine is at utilizing fuel energy. Brake thermal efficiency (BTE) describes the ratio of the engine's effective power output to the rate of chemical energy released from the fuel as it burns (Sabarish et al., 2023).

Engine thermal conditions, including coolant temperature, cylinder wall temperature, and fuel initial temperature, affect the combustion process and engine efficiency (NeuroQuantology, 2022). Suboptimal thermal conditions whether too low or too high can reduce efficiency and increase fuel consumption in diesel engines. At operating temperatures lower than optimal (over-cooling), oil viscosity increases, leading to greater friction between engine components, while low cylinder wall temperatures can prolong the ignition delay and result in incomplete combustion.

METHODOLOGY

Research Type and Approach

This study is an experimental study with a quantitative approach, using a quasi-experimental design of the two-group comparison type. The two groups being compared are the C223 diesel engine with a thermostat installed (WT/With Thermostat) and without a thermostat (WOT/Without Thermostat), which were tested using the same engine unit sequentially so that any differences in the results obtained could be attributed to the presence or absence of a thermostat, rather than to differences in engine characteristics.

Research Variables

- Independent variable: cooling system configuration (with thermostat/WT and without thermostat/WOT).
- Dependent variables: fuel consumption (ml/10 minutes and liters/hour), coolant temperature, and exhaust gas temperature.
- Control variables: standard commercial diesel fuel, engine speed of 1500 rpm, test duration of 10 minutes, and environmental conditions (room temperature of 27–32°C).

Equipment and Materials

The main equipment used included a C223 diesel engine test bench, a hydraulic dynamometer, and a standard thermostat unit. The instruments and measuring devices used are listed in Table 1.

Table 1. Measuring Tools and Instruments

No	Instrument	Function	Range	Accuracy
1	Digital Tachometer	Measures engine speed (rpm)	0–10.000 rpm	± 1 rpm
2	Graduated measuring cylinder / flow meter	Measures fuel consumption	0–1000 ml	± 1 ml
3	Digital Stopwatch	Measures test time	0–60 minutes	± 0,01 detik

4	Thermocouple / infrared thermometer	Measures coolant and exhaust gas temperatures	0–200°C	± 1°C

Data Collection Procedure

Data collection began with installing the thermostat in its factory-standard position, inspecting the cooling system to ensure it was free of leaks, and calibrating and installing all measuring instruments. The engine was then warmed up at idle speed for 10 minutes until a stable initial thermal condition was reached. Next, the engine speed is set to 1500 rpm, and once steady-state conditions are reached, data on fuel consumption, coolant temperature, and exhaust gas temperature are recorded for 10 minutes; this test under the WT configuration is repeated three times. After the WT test was completed, the engine was shut down and allowed to cool to ambient temperature; the thermostat was removed, and the cooling system was rechecked and refilled with coolant. The identical data-collection procedure including RPM, duration, and number of replicates—was then repeated for the WOT configuration, ensuring that both configurations were tested under exactly the same operating conditions.

Data Analysis Techniques

Fuel consumption data from each replication were analyzed descriptively to obtain the mean, standard deviation, and percentage difference between WT and WOT. Prior to hypothesis testing, prerequisite tests were conducted, including a normality test (Shapiro-Wilk) and a test for homogeneity of variances (Levene). The difference in average fuel consumption between WT and WOT was then tested using an independent samples t-test at a significance level of $\alpha = 0.05$. To support the analysis of the most significant operating conditions, the coolant and exhaust gas temperature data were compared against the optimal operating temperature range for diesel engines (80–95°C) and analyzed in conjunction with findings from previous studies regarding temperature profiles at various RPM levels.

RESULTS

Measurement Data

The tests were conducted at a constant engine speed of 1,500 rpm for 10 minutes for each replication. The fuel consumption results from three replications for each configuration are presented in Table 2.

Table 2. Fuel Consumption Test Results with and Without a Thermostat

Testing	Without Thermostat (ml)	With Thermostat (ml)
1	221	195
2	214	200
3	218	198

In each replication, fuel consumption in engines without thermostats was consistently higher than in engines with thermostats, and this difference was consistent across all three replications.

Descriptive Statistics and Hypothesis Testing

The average fuel consumption for WOT was 217.67 ml/10 minutes (1.31 liters/hour), while for WT it was 197.67 ml/10 minutes (1.19 liters/hour), with a percentage difference of 10.12%. A summary of the descriptive statistics is presented in Table 3.

Table 3. Descriptive Statistics of Fuel Consumption

Parameter	**Without Thermostat (WOT)**	**With Thermostat (WT)**
Average Consumption (ml/10 minutes)	217,67	197,67
Standard Deviation	3,51	2,52
Hourly Consumption (ml/hour)	1.306,02	1.186,02
Hourly Consumption (liters/hour)	1,31	1,19
Percentage Difference	-	10,12% (WT lebih hemat)

The preliminary tests indicated that the data from both groups were normally distributed (Shapiro-Wilk, WOT $p = 0.826$; WT $p = 0.714$) and that the variances were homogeneous (Levene, $p = 0.505$). The results of the independent samples t-test showed a calculated t-value of 8.032, which is greater than the critical t-value of 2.776 at $df = 4$ and $\alpha = 0.05$, with a two-tailed significance level of 0.001. Thus, there is a statistically significant difference in fuel consumption between engines with and without thermostats under the tested operating conditions.

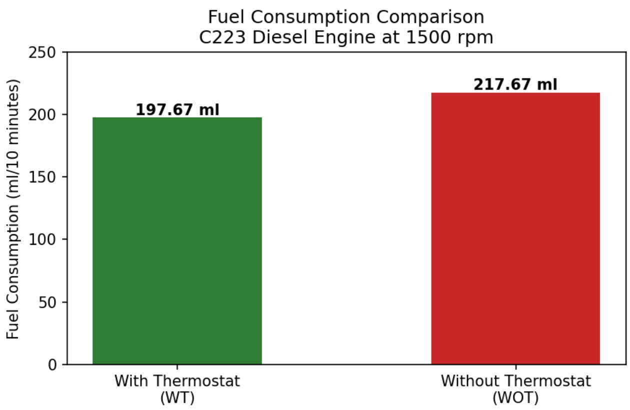

Figure 1. Comparison of Average Fuel Consumption at WT and WOT at 1500 rpm

Comparison of Coolant and Exhaust Gas Temperatures

To support the analysis of the most significant operating conditions, measurements of coolant temperature and exhaust gas temperature were also taken under steady-state conditions, as shown in Table 4 and Figure 2.

Table 4. Comparison of Coolant and Exhaust Gas Temperatures

Parameter	Without Thermostat (WOT)	With Thermostat (WT)
Average Coolant Temperature (°C)	67,3	86,8
Average Exhaust Gas Temperature (°C)	158,6	278,3

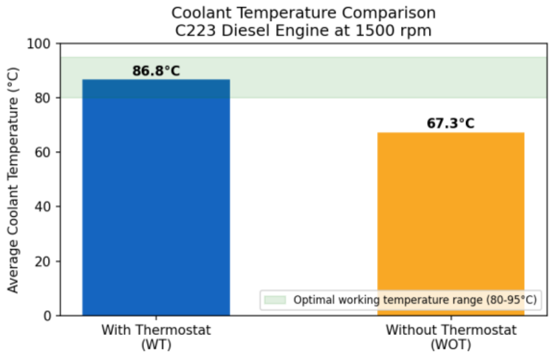

Figure 2. Comparison of Coolant Temperature with the Optimal Operating Range of a Diesel Engine (80–95°C)

The data in Table 4 and Figure 2 show that the WOT coolant temperature (67.3°C) is well below the optimal operating range of a diesel engine (80–95°C), while the WT (86.8°C) is exactly within that range. These conditions indicate that the engine without a thermostat experiences overcooling at 1500 rpm

Analysis of Operating Conditions with the Most Significant Differences

This study examined only one engine speed condition (1500 rpm); therefore, the identification of operating conditions with the most significant differences was conducted through theoretical analysis supported by test data and comparisons with previous research. Based on the principles of heat transfer and engine thermodynamics, the difference in fuel consumption between WT and WOT is estimated to be most significant at low to medium rotational speeds (idle–2,000 rpm) under light to moderate loads, for the following reasons:

1. At low RPM and low load, combustion heat is relatively low; therefore, without a thermostat, coolant circulates freely to the radiator from the start, making it difficult for the engine to reach its optimal operating temperature; the warm-up period becomes longer, and the engine operates at low efficiency for a longer duration.
2. At high RPM and high load, the heat generated is much greater, so the coolant temperature is likely to continue rising even without a thermostat; as a result, the difference in fuel consumption between WT and WOT under these conditions is estimated to be smaller than under low-load conditions, although it remains significant.

DISCUSSION

The research results confirm that the presence of a thermostat has a significant effect on the fuel consumption of the C223 diesel engine, with a 10.12% reduction in fuel consumption under WT conditions compared to WOT at 1500 rpm. This finding is consistent with (Amni et al., 2014) on the Toyota Kijang 5K engine, which reported a 10.05% increase in fuel consumption due to thermostat removal; the similarity of these figures (10.05% vs. 10.12%) indicates that the phenomenon of increased fuel consumption resulting from thermostat removal is common to both gasoline and diesel engines. (Albert K. Arkoh et al., 2021a) reported a much greater impact on the Ford VSG 413 engine, likely due to differences in engine type, load conditions, and test duration; however, the underlying pattern remains the same: engines without a thermostat always consume more fuel.

Given the focus of this study namely, under what operating conditions the differences in fuel consumption are most significant coolant temperature data is key to interpreting the results. The WOT coolant temperature, which reached only 67.3°C well below the optimal operating range of 80–95°C (Pulkrabek, 2004), in the general context of diesel engines) indicates overcooling, which leads to increased oil viscosity and friction between components, a prolonged ignition delay, and incomplete combustion. This mechanism is more dominant under low-RPM and low-load conditions, as the heat generated by combustion is insufficient to offset the rate of heat dissipation to the radiator in the absence of a thermostat. Conversely, at high RPM and high load, the heat generated tends to be greater, so an engine without a thermostat is more likely to approach its operating temperature even without automatic control; consequently, the difference in fuel consumption between WT and WOT is relatively smaller compared to that at low load.

This finding is consistent with the results of (Suryapradana & Halim, 2024), which show that at low engine speeds (560 rpm), the coolant temperature has much greater difficulty reaching the thermostat's full activation range compared to at higher engine speeds (1500 rpm), indicating a relationship between engine speed and the rate at which operating temperature is reached. This is also consistent with (Abdullah, 2021), who demonstrated that changes in thermal conditions have a significant impact on fuel consumption within a range comparable to the findings of this study (a coolant temperature difference of approximately 19.5°C correlates with a 10.12% difference in fuel consumption). Thus, it can be interpreted that low- to medium-speed operating conditions with light to moderate loads are the conditions most susceptible to the negative effects of thermostat release, and therefore represent the conditions with the most significant difference in fuel consumption between the two configurations.

CONCLUSIONS AND RECOMMENDATIONS

Based on test data at 1,500 rpm and theoretical analysis supported by previous research, it can be concluded that the difference in fuel consumption between the C223 diesel engine with and without a thermostat is estimated to be most significant under low- to medium-speed operating conditions (idle–2,000 rpm) with light- to moderate loads. Under these conditions, the engine produces relatively little combustion heat; thus, without a thermostat, the coolant that continuously circulates to the radiator makes it difficult for the engine to reach its optimal operating temperature and prolongs the engine warm-up process, which ultimately increases fuel consumption more significantly than under high-speed and high-load conditions.

FURTHER STUDY

This study has several limitations. First, the study tested only one engine speed (1500 rpm) without varying the load; therefore, the identification of operating conditions with the most significant differences is based on theoretical analysis and has not yet been empirically verified over a broader operating range. Second, the number of replicates for each configuration was relatively small (n = 3), which, although still statistically valid, limits the generalizability of the results. Third, brake Specific Fuel Consumption (BSFC) calculations were not performed due to the limited availability of a dynamometer; consequently, fuel consumption was measured only in volume per unit time, rather than in mass per unit of power. Fourth, the relatively short test duration (10 minutes) limits the understanding of the engine's thermal stability over a longer period.

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