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THE EFFECT OF THERMOSTAT CONDITION ON THERMAL STABILITY AND COMBUSTION EMISSION EFFICIENCY IN AN INLINE 4-CYLINDER GASOLINE ENGINE

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ABSTRACT
This study investigates the effect of thermostat conditions on thermal stability and exhaust emission efficiency in a 1,300 cc inline 4-cylinder gasoline engine. The novelty of this research lies in the integrated evaluation of thermostat removal and thermostat failure on both engine temperature stability and combustion emissions under identical operating conditions. A quantitative experimental method was applied using three thermostat conditions: normal thermostat, without thermostat, and clogged/damaged thermostat. Cooling system temperature and exhaust emissions (CO, HC, and CO_2) were measured at idle speed (800–1000 rpm) for 10 minutes with 2-minute intervals. The data were analyzed using descriptive comparative statistical analysis. The results show that the normal thermostat maintained the most stable operating temperature, reaching 95.8°C at the 8th minute. In contrast, the engine without a thermostat experienced unstable temperature increases and reached 93.4°C at the 10th minute, while the clogged thermostat condition produced the highest temperature of 96.6°C, indicating overheating potential. Removing the thermostat increased CO emissions from 0.01% to 0.04% and HC emissions from 31.7 ppm to 52.3 ppm. These findings confirm that thermostat condition significantly affects engine thermal stability and combustion efficiency; therefore, thermostat removal is not recommended.

Keywords: Thermostat, Engine temperature, Cooling system, Exhaust emissions

INTRODUCTION
The cooling system is one of the most important subsystems in internal combustion engines because it functions to maintain engine operating temperature within the optimal thermal range. During combustion, gasoline engines generate high thermal energy that can exceed 2,000°C inside the combustion chamber. Without proper thermal management, excessive heat accumulation may reduce engine efficiency, increase fuel consumption, accelerate component wear, and potentially cause overheating failure [1], [2]. Herefore, maintaining thermal stability is essential to ensure efficient combustion performance, engine durability, and low exhaust emissions.

One of the main components responsible for regulating engine temperature is the thermostat. The thermostat controls coolant circulation between the engine block and radiator according to engine operating temperature. Under normal conditions, the thermostat remains closed during engine warm-up and gradually opens at approximately 80–90°C to maintain stable operating temperature [3]. Previous studies reported that proper thermostat operation can improve combustion efficiency by maintaining optimal thermal conditions inside the combustion chamber. Budi et al. [4] reported that stable engine operating temperatures reduced HC emissions by approximately 18% and improved fuel combustion efficiency in gasoline engines. In addition, Nemati et al. [5] demonstrated that stable exhaust gas temperatures contributed to more efficient combustion and lower thermal fluctuation in spark ignition engines.

The In practical applications, however, many vehicle users intentionally remove the thermostat under the assumption that unrestricted coolant circulation can improve cooling performance and prevent overheating. Although this practice is common in the field, several studies indicate that thermostat removal may actually cause unstable engine temperatures and inefficient combustion. Nemati et al. [6] found that uncontrolled thermal conditions increased combustion instability and emission formation. Other studies also reported that engines operating below optimal temperature experienced increased fuel consumption and higher CO and HC emissions due to incomplete combustion [7].

Several previous studies have investigated cooling system performance and exhaust emissions separately. Some researchers focused only on radiator cooling characteristics and thermal efficiency, while others evaluated combustion emissions under different fuel or engine operating conditions [8]. However, studies simultaneously examining the influence of thermostat conditions on both cooling system thermal stability and exhaust gas emissions in gasoline engines are still limited. In particular, comparative experimental investigations involving normal thermostat conditions, thermostat removal, and clogged/damaged thermostat conditions have not been comprehensively discussed [9], [10].

Therefore, the novelty of this study lies in the simultaneous evaluation of radiator temperature characteristics and exhaust gas emission performance under three different thermostat conditions: normal thermostat, without thermostat, and clogged/damaged thermostat. This study experimentally analyzes the relationship between engine thermal stability and combustion emission efficiency in a 1,300 cc inline 4-cylinder gasoline engine. The results are expected to provide scientific insight regarding the importance of thermostat function in maintaining engine efficiency, preventing overheating, and reducing exhaust emissions in gasoline engine applications [10].

METHOD

1. Research Approach

This study employed a quantitative experimental method to investigate the effect of thermostat conditions on engine thermal stability and exhaust gas emissions in a gasoline engine. The experimental method was selected because it allows direct observation of cause-and-effect relationships between thermostat conditions and engine performance parameters under controlled operating conditions [11], [12]. The study used a completely randomized experimental design with one independent variable, namely thermostat condition, consisting of three treatment levels: (1) a normal thermostat; (2) without a thermostat; and (3) a faulty/blocked thermostat.

A quantitative approach was employed to obtain numerical data in the form of cooling system temperature and exhaust gas emissions, which were analyzed to evaluate the effect of different thermostat conditions on engine thermal stability and combustion efficiency [13], [14]. The experimental parameters observed in this study are presented in Table 1.

The collected data were analyzed using descriptive statistical methods, including mean value comparison and graphical analysis, to identify temperature and emission characteristics under each testing condition. Furthermore, a one-way Analysis of Variance (ANOVA) was applied to determine whether significant differences existed among the three thermostat conditions (normal thermostat, without thermostat, and clogged/damaged thermostat) with respect to cooling system temperature and exhaust gas emissions. The statistical analysis was conducted at a 95% confidence level (α = 0.05). If significant differences were identified, comparative interpretation was performed to evaluate the influence of thermostat condition on engine thermal performance and combustion emission efficiency.

Table 1. Relationship of Research Test Parameters

Numb.	Test Parameters	Indicator	Unit	Measurement Method	Instrument accuracy	Description
1	Thermostat Condition	a. Normal thermostat b. Without thermostat c. Blocked thermostat	-	Direct treatment on the object	-	Treated factor
2	Cooling System Temperature	a. Radiator inlet temperature b. Radiator outlet temperature	ºC	Thermocouple & thermometer	±0.5°C	Response to the treatment
3	Exhaust Gas Emissions	a. CO b. HC c. CO_2	% ppm	Gas analyzer	CO: ±0.01%; HC: ±10 ppm; CO_2: ±0.1%	Indicator of combustion efficiency
4	Rpm	Idle 800 – 1000 Rpm	Rpm	Tachometer	±10 rpm	Kept constant
5	Initial Engine Temperature	± 75ºC	ºC	Thermometer	±0.5°C	Initial test conditions
6	Ambient Temperature	29-33ºC	ºC	Ambient thermometer	±1°C	External factors
7	Testing Time	0–10 minutes (2-minute intervals)	menit	Stopwatch	±0.01 s	Test duration

To ensure the validity and reliability of the experimental data, all measuring instruments used in this study were calibrated prior to testing according to the manufacturer's standard procedures. The thermocouple and digital thermometer used for cooling system temperature measurements had an accuracy of ±0.5°C. Meanwhile, the gas analyzer (KOENG KEG-500) used for exhaust emission measurements had an error rate of ±0.01% for CO measurements, ±10 ppm for HC measurements, and ±0.1% for CO_2 measurements. Calibration procedures were conducted before each testing session to minimize measurement deviations and improve data consistency throughout the experiments.

2. Research Tools and Materials

The instruments and materials used as research tools and objects include:

a. Thermometer digital and thermocouple
b. Stopwatch
c. Gas analyzer (CO, HC, CO_2) (KEG-500 type) with the following specifications.

Table 2. Gas Analyzer Specifications

Type	Specification
Brand	KOENG
Model	KEG-500
Serial number	F2011434
Power	220V-110V AC±10%, 50/60Hz

d. Toolset

The research object or material tested is the cooling system of a 2013 Daihatsu Xenia with a 1,300 cc engine capacity, with detailed specifications presented in Table 3. In addition, the thermostat used is a standard thermostat from the 2013 Xenia in three conditions: normal, faulty, and blocked. The fuel used in this testing is RON 90 gasoline.

Table 3. Specifications of 2013 Daihatsu Xenia

Type	Specification
Engine	Liquid coolant, 4 Stroke DOHC VVTI
Fuel system	EFI
Cylinder volume	1.298 cc
Cylinder type	4 In-Line
Transmission	Manual
Fuel	Gasoline

3. Research Procedures and Process Flow

The research was conducted through several stages as described in Table 4 and the flowchart shown in Figure 1.

Table 4. Research Procedure and Process Flow

Number	Research Stages	Experimental Activities	Output Generated
1	Research Stages	a. Preparation of the test vehicle under normal operating conditions b. Preparation of research tools and materials c. Calibration of measuring instruments d. Installation of thermocouples in the cooling system	The system is ready for testing and all instruments are properly calibrated and accurate
2	Pre-testing	a. Initial inspection of the cooling system b. Determination of the initial engine temperature condition (±75°C) c. Ensuring stable engine speed at idle (800–1000 rpm)	The initial testing conditions are standardized
3	Experiment 1	Normal Thermostat a. The engine is operated under idle conditions b. Temperature measurements are recorded at 2-minute intervals for 10 minutes c. Exhaust gas emissions are measured	Temperature and emission data under normal operating conditions
4	Experiment 2	Without Thermostat a. The thermostat is removed b. The test is conducted using the same procedure c. Temperature and emission data are recorded	Temperature and emission data under conditions without a thermostat
5	Experiment 3	Clogged/Damaged Thermostat a. Using a clogged/damaged thermostat b. The test is conducted using the same procedure	Temperature and emission data under abnormal operating conditions

Number	Research Stages	Experimental Activities	Output Generated
		c. Temperature and emission data are recorded	
6	Data Processing	a. Organization of data into tables and graphs b. Comparison of results across different conditions c. Analysis of the relationship between temperature and emissions	Data that have been processed and analyzed
7	Analyze	Interpreting test results, evaluating the effect of the thermostat, and comparing with theory and previous studies	Scientific Analysis
8	Conclusions	Formulation of conclusions and recommendations	Conclusions and Recommendations

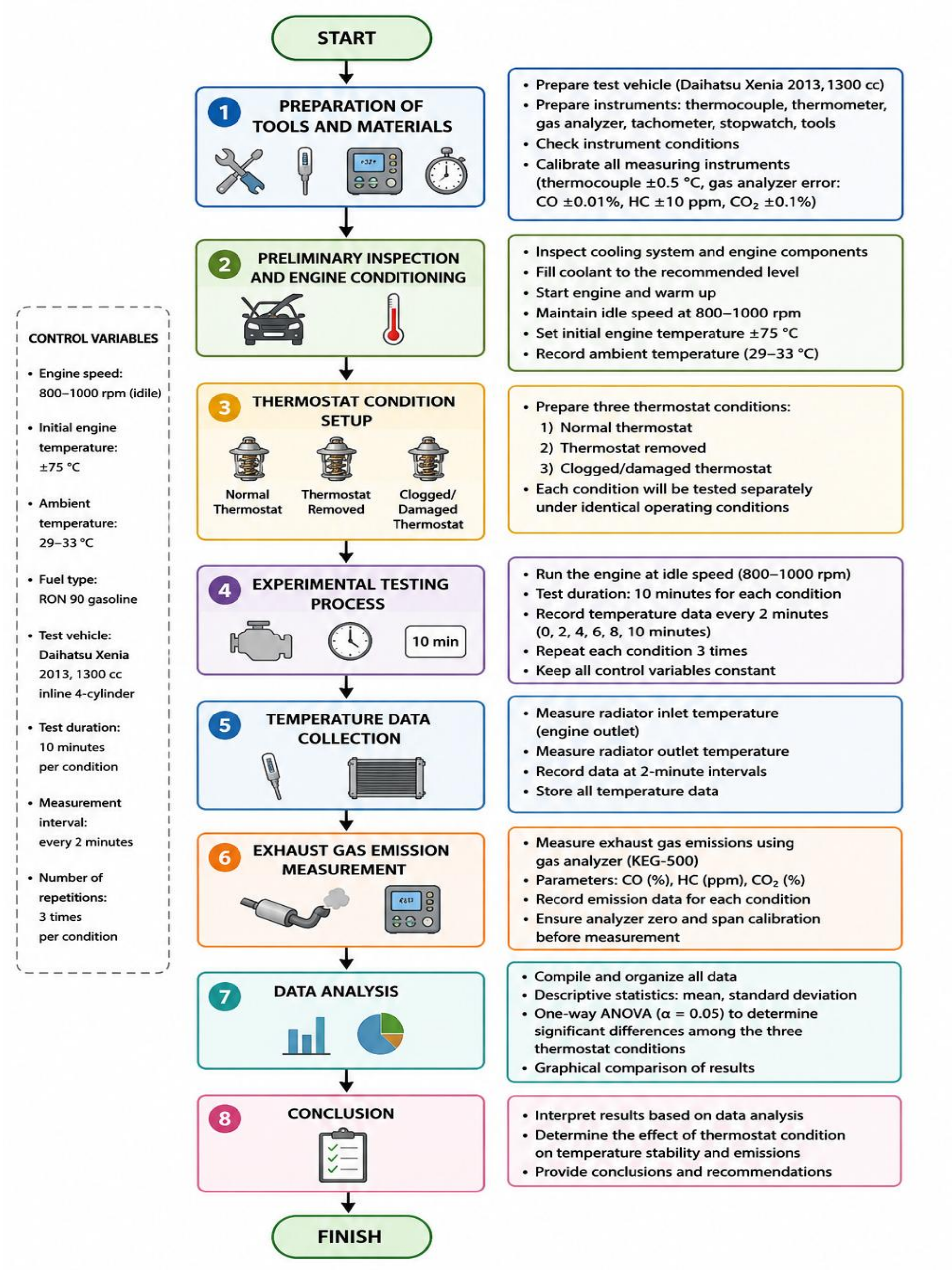

Figure 1. Research Flowchart

RESULTS AND DISCUSSION

The experiments were carried out under three conditions: (1) a standard thermostat, (2) without a thermostat, and (3) a clogged/damaged thermostat. The observed parameters included cooling system temperature and exhaust gas emissions.

1. Results of Cooling System Temperature Testing

Overall, the results demonstrate distinct temperature rise patterns across the different testing conditions:

a. Normal thermostat
   The temperature increased to reach the optimal operating temperature (~95.8°C at the 8th minute), after which it decreased and stabilized.
b. Without thermostat
   The temperature increased gradually but exhibited instability and continued rising until the end of the test (~93.4°C at the 10th minute).
c. Clogged/Damaged Thermostat
   The temperature increased more rapidly and reached the highest value (~96.6°C), indicating a tendency toward overheating conditions.

The emission measurement results indicate significant differences across the tested conditions.

Table 5. Results of Thermostat Testing

Thermostat condition	CO (%)	HC (ppm)	CO_2 (%)
Normal	0.01	31.7	8.3
without thermostat	0.04	52.3	8.5
Clogged/damaged	0.01	21	8.6

It is observed that the absence of a thermostat results in higher CO and HC emissions compared to normal operating conditions.

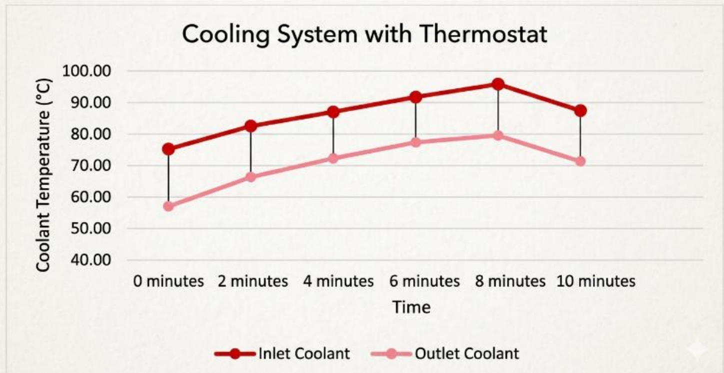

Figure 2. Comparison of Radiator Inlet and Outlet Temperatures under Normal Thermostat Conditions

Figure 2 shows that under normal thermostat conditions, the engine temperature increased gradually during the initial operating period and reached an optimal operating temperature of approximately 95.8°C at the 8th minute before stabilizing. The radiator inlet temperature was consistently higher than the outlet temperature, indicating that the radiator effectively dissipated heat from the coolant before it recirculated into the engine.

This condition occurred because the thermostat functioned properly by restricting coolant circulation during engine warm-up and gradually opening when the coolant temperature reached approximately 80–90°C. The controlled coolant circulation allowed the engine to achieve thermal equilibrium more rapidly and maintain stable operating conditions. According to heat transfer theory, stable coolant circulation improves heat dissipation efficiency by balancing heat absorption in the engine block and heat release in the radiator. Stable operating temperature also contributes to better combustion chamber conditions and thermal efficiency.

These findings are consistent with previous studies reporting that proper thermostat operation improves engine thermal stability and prevents excessive temperature fluctuations [8]. In addition, stable engine temperatures enhance combustion quality because fuel vaporization and flame propagation occur more efficiently under optimal thermal conditions.

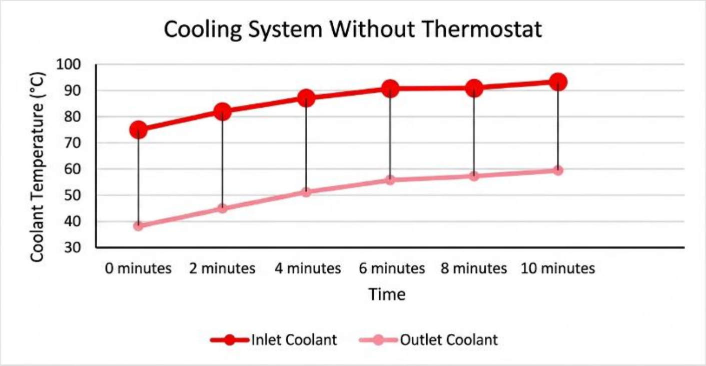

Figure 3. Comparison of Radiator Inlet and Outlet Temperatures without a Thermostat

Figure 3 illustrates that the engine temperature increased continuously and tended to fluctuate under thermostat removal conditions. Unlike the normal thermostat condition, the temperature did not stabilize and reached approximately 93.4°C at the end of the testing period. The temperature difference between radiator inlet and outlet also became less stable, indicating uncontrolled coolant circulation.

This phenomenon occurred because removing the thermostat caused coolant to circulate continuously from the beginning of engine operation. As a result, excessive heat dissipation occurred during the warm-up phase, preventing the engine from quickly reaching its optimal operating temperature. In thermal management systems, uncontrolled coolant flow reduces the effectiveness of temperature regulation and causes unstable heat distribution inside the engine.

From the combustion perspective, unstable engine temperatures negatively affect fuel atomization and air–fuel mixture preparation. Fuel vaporization becomes less efficient at non-optimal temperatures, resulting in incomplete combustion and increased HC and CO emissions. Furthermore, unstable thermal conditions can interfere with flame propagation inside the combustion chamber, reducing combustion efficiency.

These findings are consistent with studies conducted by Nemati et al. [5] and Dika [8], which reported that unstable thermal conditions and low engine operating temperatures contribute to increased exhaust emissions and reduced combustion efficiency. Therefore, thermostat removal may increase fuel consumption and reduce overall engine performance.

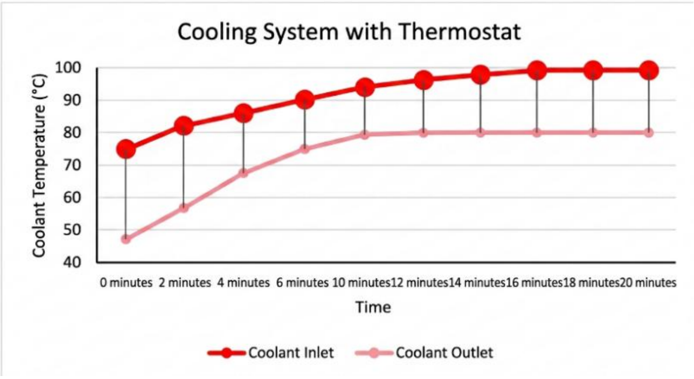

Figure 4. Comparison of Radiator Inlet and Outlet Temperatures with a Clogged/Damaged Thermostat

Figure 4 shows that the clogged/damaged thermostat condition produced the highest temperature increase among all testing conditions, reaching approximately 96.6°C. The radiator inlet temperature increased rapidly, while the outlet temperature exhibited limited reduction, indicating restricted coolant circulation and poor heat dissipation performance.

This condition occurred because the clogged or damaged thermostat restricted coolant flow between the engine and radiator. Consequently, heat accumulated inside the engine block and could not be effectively transferred to the radiator. According to engine cooling theory, restricted coolant circulation decreases convective heat transfer efficiency and significantly increases the risk of overheating.

Excessively high engine temperatures may initially improve fuel evaporation and oxidation reactions; however, prolonged overheating conditions can damage engine components, reduce lubricant performance, and accelerate material wear. In addition, unstable high temperatures may lead to abnormal combustion phenomena such as knocking and thermal stress on engine components.

These findings are consistent with previous studies indicating that cooling system malfunctions and restricted coolant circulation significantly increase engine operating temperatures and reduce engine durability [15], [16]. Therefore, maintaining proper thermostat function is essential not only for thermal stability but also for long-term engine reliability and maintenance efficiency.

2. Discussion

a. The Effect of the Thermostat on the Cooling System Temperature

The experimental results demonstrate that thermostat condition significantly affects engine thermal stability and coolant temperature distribution. Under normal thermostat conditions, the engine temperature increased gradually and reached an optimal operating temperature of approximately 95.8°C before stabilizing. This indicates that the thermostat successfully regulated coolant circulation according to engine thermal demand. The thermostat remained closed during the initial warm-up stage, allowing heat to accumulate inside the engine block and enabling the engine to rapidly achieve optimal operating temperature. Once the coolant temperature reached approximately 80–90°C, the thermostat gradually opened and allowed coolant circulation toward the radiator, thereby maintaining thermal equilibrium within the cooling system [17], [15].

From the perspective of heat transfer theory, proper thermostat operation improves convective heat dissipation efficiency because coolant circulation occurs according to the engine thermal load. Stable coolant flow allows the radiator to dissipate heat more effectively and prevents excessive thermal fluctuations. This condition is important because stable engine temperature contributes to improved lubrication performance, combustion stability, and thermal efficiency. Similar findings were reported by Tetik et al. [13], who stated that stable engine thermal conditions improve combustion consistency and reduce thermal stress on engine components.

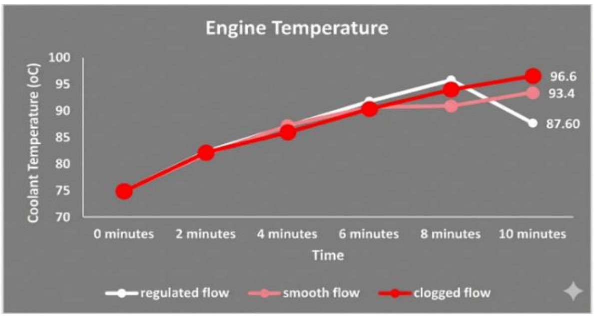

Figure 5. Comparison of Engine Temperature

In contrast, removing the thermostat caused uncontrolled coolant circulation throughout the testing process. The temperature profile under thermostat removal conditions showed unstable increases and continuous fluctuations, reaching approximately 93.4°C at the end of the experiment without achieving thermal stabilization. This phenomenon occurred because coolant flowed continuously from engine start-up, causing excessive heat dissipation during the warm-up phase. As a result, the engine required a longer time to reach optimal operating temperature, and thermal equilibrium inside the engine became unstable.

Thermally unstable operating conditions negatively affect engine efficiency because heat distribution inside the combustion chamber becomes inconsistent. Under low or fluctuating temperatures, fuel atomization becomes less effective, reducing combustion quality and increasing incomplete combustion products. Frey et al. [14] reported that unstable thermal conditions increase combustion irregularities and emission formation due to non-uniform temperature distribution inside the combustion chamber. Thavamony [16] also found that engines operating below optimal temperature exhibited higher HC and CO emissions because incomplete oxidation reactions occurred during combustion.

Meanwhile, the clogged or damaged thermostat condition produced the highest temperature increase, reaching approximately 96.6°C. This condition indicates restricted coolant circulation between the engine block and radiator. When coolant flow is obstructed, heat accumulates inside the engine and cannot be transferred effectively to the radiator. Consequently, the engine experiences excessive thermal loading and a greater risk of overheating. According to convective cooling theory, reduced coolant flow decreases the heat transfer coefficient, thereby reducing radiator cooling effectiveness.

Excessive engine temperatures may initially improve fuel evaporation; however, prolonged overheating conditions can reduce lubricant viscosity, accelerate component wear, and increase thermal stress on pistons, cylinder walls, and cylinder heads. Saleh et al. [15] explained that continuous thermal stress significantly contributes to fatigue failure and crack propagation in engine components. Similar findings were also reported by Li et al. [16], who stated that abnormal thermal conditions accelerate mechanical degradation and reduce engine durability [15].

Overall, these findings confirm that the thermostat plays a crucial role in maintaining engine thermal stability by regulating coolant circulation according to operating temperature. Proper thermostat performance not only prevents overheating but also improves combustion stability, fuel economy, and long-term engine durability. Therefore, thermostat removal is not recommended in gasoline engine applications because it reduces thermal control effectiveness and negatively affects engine operating efficiency [16].

b. The Effect of the Thermostat on Exhaust Gas Emissions

The exhaust gas emission results indicate that thermostat condition significantly influences combustion quality and emission characteristics in the gasoline engine. Figure 6 shows that the engine operating without a thermostat produced the highest CO and HC emissions compared to the other testing conditions. Under thermostat removal conditions, CO emissions increased from 0.01% to 0.04%, while HC emissions increased from 31.7 ppm to 52.3 ppm. This condition indicates that unstable engine operating temperatures negatively affect combustion efficiency and increase incomplete combustion products. In contrast, the normal thermostat condition produced lower CO and HC emissions because the engine temperature remained within the optimal operating range [7].

From the combustion theory perspective, stable engine temperature is essential for proper fuel atomization, air–fuel mixing, and flame propagation inside the combustion chamber. Under normal thermostat conditions, the engine reached its optimal operating temperature more quickly, allowing gasoline to vaporize more effectively and improving combustion completeness. Consequently, the oxidation process became more efficient, reducing CO and HC emissions. These findings are consistent with Saleh [15], who reported that stable engine temperatures improve combustion efficiency and reduce incomplete combustion products in gasoline engines [18], [19].

In contrast, thermostat removal caused uncontrolled coolant circulation and unstable thermal conditions. Excessive cooling during the warm-up phase reduced fuel vaporization quality and disrupted flame propagation, resulting in incomplete combustion. This phenomenon increased HC emissions due to unburned fuel and increased CO emissions because carbon oxidation reactions did not occur completely. Similar results were reported by Nemati et al. [6], who stated that unstable combustion temperatures significantly contribute to emission formation and reduced combustion stability in internal combustion engines [18], [19].

Figure 6 also shows that the clogged/damaged thermostat condition produced the highest CO_2 emission value of 8.6%, indicating more intensive oxidation reactions at elevated temperatures. Higher temperatures generally improve fuel evaporation and combustion completeness; however, excessive temperatures may increase the risk of overheating, lubricant degradation, and engine component wear. These findings are consistent with Saleh et al. [15], who explained that excessive thermal loading accelerates material fatigue and reduces engine durability. Therefore, maintaining proper thermostat performance is essential not only for reducing exhaust emissions but also for improving fuel economy, engine reliability, and long-term maintenance performance [19], [4].

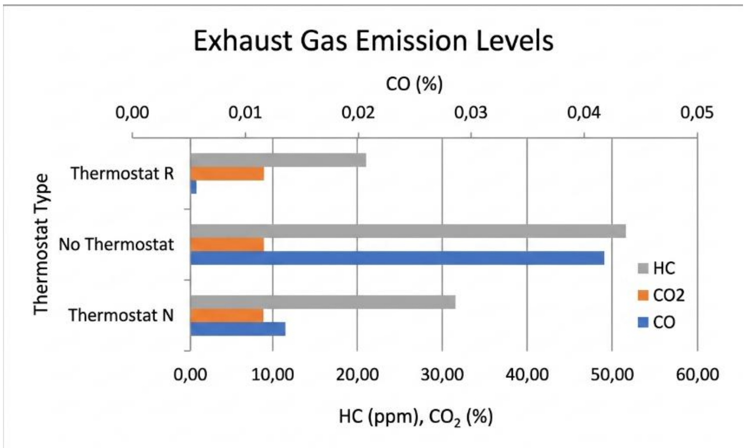

Figure 6. Emission comparison graph

c. Analysis of the Relationship Between Temperature and Combustion Efficiency

The experimental results indicate a strong relationship between engine operating temperature and combustion efficiency. Under normal thermostat conditions, the engine temperature remained stable within the optimal operating range, resulting in lower CO and HC emissions compared to the other testing conditions. Stable thermal conditions improve fuel vaporization, air–fuel mixing, and flame propagation inside the combustion chamber, allowing combustion to occur more completely and efficiently. Consequently, oxidation reactions become more effective, reducing incomplete combustion products and improving thermal efficiency. These findings are consistent with Liu et al. [20], who reported that stable thermal management improves combustion consistency and engine operating performance.

In contrast, thermostat removal caused unstable engine temperatures and continuous thermal fluctuations due to uncontrolled coolant circulation. Excessive cooling during the engine warm-up phase reduced combustion chamber temperature and negatively affected fuel atomization. Under non-optimal thermal conditions, gasoline droplets do not vaporize completely, resulting in uneven air–fuel mixture distribution and incomplete combustion. This phenomenon explains the increase in HC and CO emissions observed in the thermostat removal condition. Similar findings were reported by Gulum [3], who stated that engines operating below optimal temperature exhibit reduced combustion efficiency and increased incomplete combustion emissions.

Meanwhile, the clogged or damaged thermostat condition produced excessively high operating temperatures because coolant circulation was restricted. Higher combustion temperatures may improve oxidation reactions and increase combustion completeness, as indicated by the higher CO_2 emission value. However, excessive thermal conditions also increase the risk of overheating, lubricant degradation, and abnormal combustion phenomena such as knocking. Nemati et al. [6] explained that uncontrolled combustion temperatures significantly affect combustion stability and engine reliability. Therefore, proper thermostat performance is essential not only for maintaining temperature stability but also for improving combustion efficiency, fuel economy, exhaust emission control, and long-term engine durability.

CONCLUSION

This study confirms that thermostat condition significantly affects engine thermal stability, combustion efficiency, and exhaust gas emissions in a gasoline engine. A properly functioning thermostat maintains optimal engine operating temperature by regulating coolant circulation, thereby improving fuel vaporization, combustion stability, and oxidation efficiency, which results in lower CO and HC emissions. In contrast, thermostat removal causes unstable thermal conditions and incomplete combustion due to uncontrolled coolant flow, while a clogged or damaged thermostat increases the risk of overheating because of restricted heat dissipation. The findings also demonstrate that engine temperature has a direct relationship with combustion quality and emission formation. The novelty of this study lies in the simultaneous evaluation of cooling system temperature characteristics and exhaust gas emissions under three different thermostat conditions. Therefore, proper thermostat maintenance is essential to improve fuel economy, reduce exhaust emissions, maintain engine durability, and support reliable vehicle operation.

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