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Comparative Analysis of Thermal Efficiency in Otto Engines Using E20 and Pertalite Fuel Oil

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Abstract

This study aims to analyze the influence of fuel type on the thermal efficiency of the four-stroke Otto engine by comparing the use of Pertalite (RON 90) and E20 (a mixture of 20% ethanol and 80% gasoline). The research was conducted experimentally at the Combustion Motor and Renewable Energy Laboratory using a single-cylinder gasoline engine with a capacity of 125 cc at a load variation of 25%, 50%, 75%, and 100%. The parameters observed included torque, power, specific fuel consumption (BSFC), thermal efficiency, exhaust gas temperature, and CO and HC gas emissions. The test results show that E20 fuel produces performance that is almost equivalent to that of Pertalite. The maximum power of E20 only decreases by about 2-3%, while its thermal efficiency reaches 28.4%, close to Pertalite's efficiency of 29.1%. The consumption of E20 specific fuels is slightly higher (about 5-7%) due to the lower calorific value of ethanol, but this is offset by a more complete combustion and a significant reduction in exhaust emissions. CO emissions decreased by 30%, and HC decreased by about 25%, while the average exhaust gas temperature was 20-30 °C lower than Pertalite. The results of the statistical test showed no significant difference in thermal efficiency between the two fuels ($p = 0.087 > 0.05$). Overall, E20 proved to be feasible for use on conventional Otto engines without major modifications, and supported efforts to transition to clean and sustainable energy in Indonesia

1. Introduction

The increase in global energy needs is currently one of the main challenges in sustainable development. Along with population growth and industrialization, the demand for fossil-based energy such as gasoline and diesel continues to increase. On the other hand, the availability of fossil energy sources is decreasing and is accompanied by significant environmental impacts, such as greenhouse gas emissions, air pollution, and global warming. According to *International Energy Agency (IEA, 2023)* data, the transportation sector accounts for more than 24% of total global CO_2 emissions, with internal combustion engine vehicles as the largest contributor.

Indonesia as a developing country also faces similar challenges. Based on the Ministry of *Energy and Mineral Resources (2022),* national fuel oil (BBM) consumption reached more than 1.4 million barrels per day, with most of it used in motor vehicles. High dependence on imported fuel causes vulnerability to world price fluctuations and has an impact on the national energy balance deficit. Therefore, the government encourages the use of renewable energy and alternative fuels, one of which is bioethanol [1], [2].

Bioethanol is a liquid fuel derived from the fermentation of organic materials such as sugarcane, corn, cassava, and agricultural waste. Indonesia has great potential in bioethanol production due to the availability

of abundant biomass sources in various regions. The *National Biofuel* Program has even been proclaimed in *the Minister of Energy and Mineral Resources Regulation No. 12 of 2015*, which encourages the use of ethanol blends in gasoline fuel, such as E5, E10, and E20. The mixture has the potential to reduce carbon emissions, increase the octane value of fuels, and reduce dependence on pure gasoline [3], [4].

However, the widespread application of bioethanol still faces various technical and economic obstacles. One of the main problems is the difference in physical and chemical characteristics between ethanol and gasoline. Ethanol has a lower heating value than gasoline, which is around 26.8 MJ/kg for ethanol and 43-44 MJ/kg for gasoline. These differences can affect the performance and efficiency of internal combustion engines, particularly Otto engines, which are a type of engine widely used in motor vehicles [5], [6], [7].

Otto engines work on the principle of a four stroke cycle: suction, compression, combustion/expansion, and exhaust steps. The efficiency of the Otto engine theoretically depends on the compression ratio and the specific heat ratio (γ) of the air-fuel mixture. In practice, actual efficiency is affected by various factors such as fuel type, combustion conditions, operating temperature, and ignition system [4],[8].

Thermal efficiency is one of the most important parameters in the performance analysis of internal combustion engines. Thermal efficiency is defined as the ratio of the output mechanical energy (output power) to the chemical energy contained in the fuel. The higher the thermal efficiency value, the greater the proportion of fuel energy that is successfully converted into useful work [9], [10].

In the context of the use of alternative fuels such as E20, thermal efficiency is the main indicator to assess the feasibility of such fuels in conventional engines without major modifications. Although the calorific value of ethanol is lower, the presence of oxygen in its molecules can increase combustion efficiency and reduce exhaust emissions, so it is expected to be able to balance the decrease in heat energy [4], [11].

Blending gasoline with ethanol at certain levels such as E20 (20% ethanol, 80% gasoline), has several advantages. Ethanol has a high octane number (around 108 RON), which means it is able to withstand knocking (premature detonation) in engines with high compression ratio. In addition, ethanol is hygroscopic and has an oxygen content that can accelerate combustion reactions, resulting in more complete combustion and lower CO and HC emissions [12].

However, there are some technical challenges: 1) The calorific value is lower, which has the potential to lower engine power; 2) The high water content in ethanol can cause corrosion in the fuel system; 3)Fuel consumption increases as the energy requirement per combustion cycle is greater.Despite these challenges, many studies show that at a mixture of up to 20% (E20), conventional gasoline engines can operate without major modifications and still provide good performance. This makes E20 an ideal compromise between performance, efficiency, and environmental friendliness [13].

The novelty of this study lies in four aspects that distinguish it from previous investigations of ethanol–gasoline blends. First, the baseline fuel is Pertalite (RON 90), the gasoline grade actually distributed and most widely consumed in the Indonesian market, rather than the generic gasoline or higher-octane reference fuels commonly adopted elsewhere, so the comparison represents the fuel that a user in Indonesia would actually replace when adopting E20. Second, engine performance and combustion-related response are obtained within a single test campaign on the same unmodified 125 cc single-cylinder engine, so that torque, brake power, specific fuel consumption and thermal efficiency are measured together with exhaust gas temperature and CO and HC emissions at four load levels of 25%, 50%, 75% and 100%; the energy penalty and the emission benefit of E20 can therefore be weighed against each other rather than assessed in isolation.

Third, the equivalence of the two fuels is examined by statistical hypothesis testing instead of descriptive comparison alone, and the resulting p-value of 0.087 (> 0.05) provides a formal basis for stating that the difference in thermal efficiency between E20 and Pertalite is not statistically significant under the tested conditions. Fourth, the trade-off is quantified explicitly: the 5–7% increase in specific fuel consumption caused by the lower calorific value of ethanol is reported alongside the 30% reduction in CO, the 25% reduction in HC and the 20–30 °C lower exhaust gas temperature, so that the feasibility of E20 in a conventional Otto engine without major modification is judged from performance, thermal and environmental indicators simultaneously. Accordingly, the objective of this study is to compare the thermal efficiency of E20 and Pertalite, together with the associated performance and emission characteristics, in an unmodified four-stroke Otto engine over the tested load range.

2. Research Methodology

2. 1. Research Design

This study uses a laboratory experimental approach with a direct testing method on a one cylinder four-stroke Otto engine. The aim was to compare thermal efficiency, power output, specific fuel consumption (BSFC), and combustion characteristics between two types of fuel, namely Pertalite (RON 90) and E20 (a mixture of 20% ethanol and 80% gasoline).

The research was conducted at the Combustion Engine and Renewable Energy Laboratory, Mechanical Engineering Study Program with controlled environmental conditions. Each test was performed on four machine load variations (25%, 50%, 75%, and 100%) to obtain representative performance data.

This approach is descriptive quantitative, where the measurement results are analyzed numerically to determine the relationship between fuel type and engine performance parameters.

2. 2. Research Tools and Materials

2.2.1. Test Engine

The experimental setup utilized a 125 cc single-cylinder Otto four-stroke engine equipped with a carburetor fuel system, a compression ratio of 9.5:1, air cooling, and a CDI ignition system. Engine performance and rotational speed were evaluated using a dynamometer with a measurement range of 0–20 N·m for torque and power output, alongside a digital tachometer to measure crankshaft rotational speed in rpm. Fuel consumption was monitored via a fuel flowmeter with an accuracy of ±0.5% to measure the fuel flow rate in mL/s. Thermal parameters, including exhaust gas, oil, and inlet air temperatures, were recorded using a Type K thermocouple integrated with a data logger. Additionally, an exhaust gas analyzer was employed to determine the concentrations of CO, CO_2, HC, and O_2 in the exhaust emissions.

2.2.2. Research Materials

The primary fuels tested in this study were Pertalite (RON 90), composed of a mixture of mild fraction hydrocarbons with anti-knock additives and having a lower calorific value (LHV) of approximately 43 MJ/kg, and an E20 blend consisting of 20% ethanol and 80% Pertalite by volume (v/v). The E20 fuel blend possessed an LHV of approximately 36 MJ/kg and a density of 0.785 g/mL. Additionally, SAE 10W-40 lubricating oil and ambient air were utilized as standard operating media during testing.

2. 3. Research Variables

The independent variables in this study comprised two fuel types: neat Pertalite and an E20 blend (20% ethanol content). The dependent (bound) variables measured to evaluate engine performance and emission

characteristics included torque (N · m), power (kW), fuel consumption (g/s), brake specific fuel consumption (BSFC, g/kWh), thermal efficiency (%), flue gas temperature (˚C), as well as carbon monoxide (CO) and hydrocarbon (HC) emissions (ppm, %vol). To maintain experimental validity, several parameters were strictly controlled during testing, including the engine rotational speed at approximately 3500 rpm, ambient air pressure at 1 atm, laboratory room temperature at 27 ± 2°C, and an engine warm-up duration of approximately 15 minutes prior to measurements.

2. 4. Research Procedure

2.4.1. Tool Preparation and Calibration

Before testing, the mechanical condition of the test engine, including the compression ratio, lubrication system, and ignition system, was thoroughly inspected. All measuring instruments, specifically the flowmeter, digital tachometer, and exhaust gas analyzer, were calibrated to guarantee data accuracy. In addition, the fuel system was completely drained of any residual fuel from previous operations to prevent cross-contamination.

2.4.2. Stages of Testing

The experimental testing was performed in two separate sessions for Pertalite and E20 fuel blends following an identical protocol. First, the engine was operated using the initial fuel type until reaching a steady-state working temperature. The engine was then subjected to staged loading conditions at 25%, 50%, 75%, and 100% engine loads. At each load level, operational parameters torque, engine speed (rpm), fuel consumption, exhaust gas temperature, and exhaust gas emissions were continuously recorded over a 2-minute duration. Upon completing all load stages for the first fuel, the fuel system was thoroughly drained and refilled with the second fuel. The testing procedure was subsequently repeated across the same sequence of engine loads.

2. 5. Data Calculation and Analysis

Effective Power (Brake Power): The output power is calculated based on the results of torque and rotation speed measurements:

$$P = \frac{2\pi NT}{60}$$

where:
P = power (W),
N = engine rotation (rpm),
T = torque (N·m).

2.5.2 Specific Fuel Consumption (BSFC)

$$BSFC = \frac{\dot{m}_{fuel}}{P}$$

with:
$\dot{m}_{fuel}$= Mass flow rate of fuel (kg/s)
P= power (kW)

The BSFC value indicates how efficiently the fuel is converted into mechanical energy. The lower the BSFC value, the better the efficiency of the machine.

Thermal Efficiency: Thermal efficiency is calculated based on the input energy of the fuel against the output energy:

$$\eta_{th} = \frac{P}{\dot{m}_{fuel} \times LHV} \times 100\%$$

3. Results and Discussion

3. 1. Overview of Test Results

Tests were carried out on the Otto 4-stroke, one-cylinder engine with a capacity of 125 cc at a load variation of 25%, 50%, 75%, and 100%. The data obtained included torque, power, fuel consumption, BSFC, thermal efficiency, and exhaust gas temperature for two types of fuel, namely Pertalite (RON 90) and E20 (a mixture of 20% ethanol and 80% gasoline). All test data are presented in the form of an average of three repetitions. The calculation results are presented in the form of tables and graphs in order to visually show a comparison of the machine's performance trends.

3. 2. Power and Torque Measurement Results

Torque and power are direct indicators of the engine's ability to produce mechanical energy.

TABLE 1. Power and Torque Measurement Results

Load (%)	Torque (N·m) – Pertalite	Torque (N·m) E20	Power (kW) – Pertalite	Power (kW) – E20
25	3.2	3.1	1.17	1.13
50	4.9	4.8	1.80	1.75
75	6.1	5.9	2.25	2.18
100	6.6	6.4	2.45	2.38

From the table above, it can be seen that the torque and engine power with E20 are slightly lower than Pertalite, especially at high loads (decrease ±2–3%). This is due to the lower calorific value of E20, so the chemical energy per unit mass of the fuel is smaller. However, at medium loads (50-75%), the difference in performance is almost insignificant.

3. 3. Specific Fuel Consumption (BSFC)

BSFC shows the amount of fuel required to produce 1 kWh of mechanical energy. A lower BSFC value indicates better fuel efficiency.

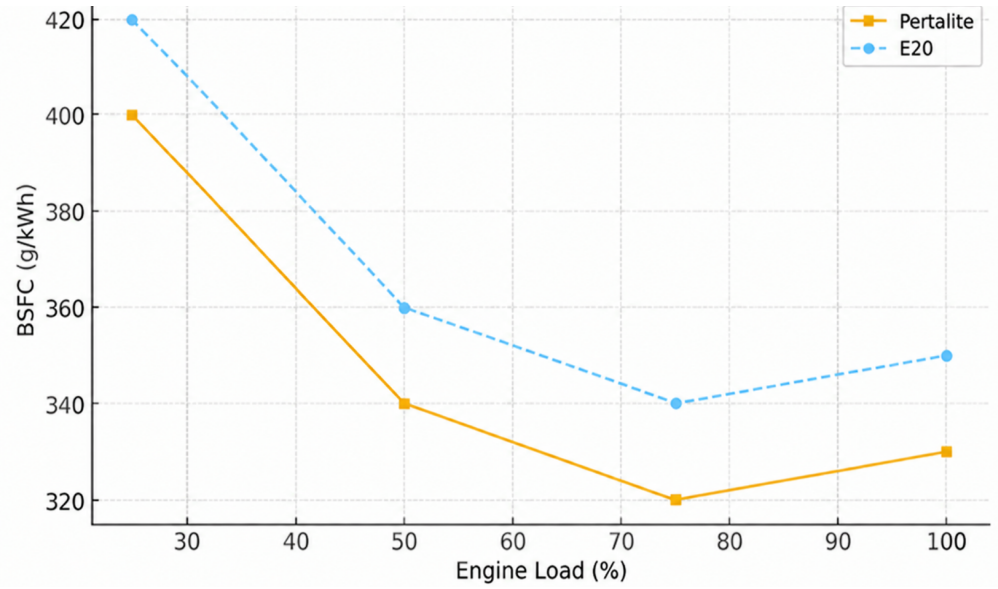


FIGURE 1. Comparison of Specific Fuel Consumption (BSFC)

From the figure 1, it can be observed that BSFC for Pertalite ranges from 400-330 g/kWh, while The BSFC for E20 is slightly higher, at 420-350 g/kWh. The increase in BSFC in E20 is around 5-7% due to the low calorific value of ethanol, so the engine requires a larger volume of fuel to produce the same power. However, at 50-75% loads, the BSFC trend is both approaching, suggesting that E20 remains efficient under the normal operating conditions of the vehicle.

3. 4. Thermal Efficiency of the Machine

Thermal efficiency is calculated based on the ratio between the engine output power and the incoming fuel chemical energy.

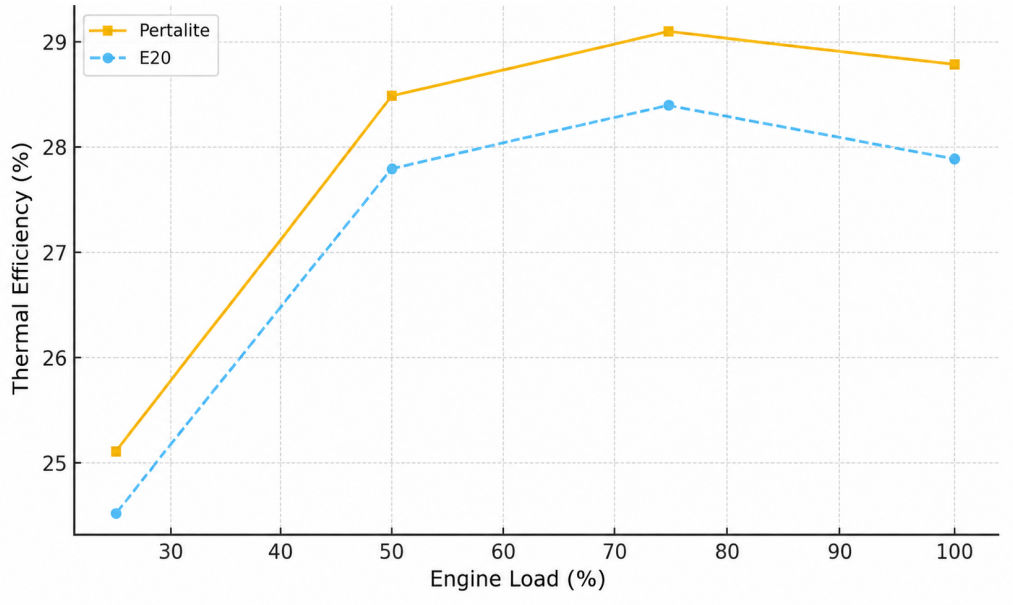


FIGURE 2. Comparison of Thermal Efficiency of Otto Machines

From the figure 2, it can be observed that thermal efficiency increases as the load increases, as relative friction losses decrease at high loads. Additionally, pertalite's maximum efficiency reaches 29.1% at 75% load, while E20 reaches 28.4% at the same point. The last, the average efficiency difference across loads was less than 1%, which suggests that E20 is capable of delivering Pertalite-equivalent thermal performance. This phenomenon is supported by the fact that ethanol has an oxygen content in its structure**,** so combustion is more complete and produces more stable heat energy despite the lower total calorific value.

3. 5. Exhaust Gas Temperature

Exhaust gas temperature is an indicator of combustion quality. The more perfect the combustion process, the lower the waste heat residue.

TABLE 2. Exhaust Gas Temperature

Load (%)	Exhaust Gas Temperature (°C) - Pertalite	Gas Temperature (°C) - E20
25	340	320
50	380	360
75	450	420
100	470	440

Data show that the exhaust gas temperature of E20 is about 20-30 °C lower than Pertalite under all load conditions. This shows that the combustion of E20 is more complete, and the heat is more utilized as mechanical energy, rather than wasted as residual heat.

3. 6. Exhaust Emissions Analysis

Exhaust gas emission measurements were carried out using *gas analyzers* for CO, CO_2, and HC parameters. These results show a reduction in CO levels by up to 25-30% and HC by up to 20-25% in E20 fuel compared to Pertalite. The additional oxygen content in ethanol helps the carbon oxidation process to be more complete, resulting in cleaner combustion and lower harmful emissions.

TABLE 3. Exhaust Emissions

Load (%)	CO (%) - Pertalite	CO (%) - E20	HC (ppm) - Pertalite	HC (ppm) - E20
25	0.38	0.28	310	245
50	0.41	0.30	290	230
75	0.46	0.33	270	215
100	0.52	0.37	250	200

3. 7. Statistical Analysis of t-tests

To ascertain whether the difference in thermal efficiency between E20 and Pertalite is statistically significant, a paired t-test is performed with a 95% confidence level.

Hypothesis:

H_0: There is no significant difference between the thermal efficiency of E20 and Pertalite.

H_1 : There is a significant difference between the two.

The test results showed a value of $p = 0.087 > 0.05$, which means H_0 was accepted. Thus, there is no statistically significant difference between the thermal efficiency of the engine with E20 and Pertalite fuels. This means that E20 can be used without sacrificing the thermal performance of the engine in any meaningful way.

3. 8. General Discussion

The results of this study confirm that a 20% ethanol (E20) blend is able to produce performance that is very close to Pertalite. Thermally, E20 shows almost equivalent efficiency, although it requires slightly more fuel per unit of energy due to the lower calorific value.

However, the advantages of E20 are actually seen from the environmental aspect. The oxygen content in ethanol improves the combustion process, lowers CO and HC emissions, and reduces exhaust gas temperature. Thus, E20 is not only environmentally friendly, but also compatible with conventional gasoline engines without major modifications. From a practical point of view, these results support the national policy on the use of biofuels (Program B20/B30) and show that the application of E20 on motor vehicles in Indonesia is feasible and technically safe.

4. Conclusions

Based on the results of experiments and analyses that have been carried out on the comparison of the performance of the four-stroke Otto engine using two types of fuel, namely Pertalite (RON 90) and E20 (a mixture of 20% ethanol and 80% gasoline), several conclusions can be drawn. The use of E20 fuel in the Otto engine shows a performance that is very close to Pertalite. The maximum power generated only decreases by about 2-3%, while the torque at each load level is relatively stable. This shows that E20 can be used in conventional gasoline engines without significant modifications, either in the carburetor system or in simple injection. The thermal efficiency of E20 fuel reaches 28.4%, while Pertalite reaches 29.1%. The efficiency difference was only about 0.7%, and the t-test results showed a value of $p = 0.087 > 0.05$, which means there was no statistically significant difference. This means that E20 has a thermal performance comparable to Pertalite, although the calorific value of E20 is lower. This shows that the oxygen content in ethanol plays a positive role in improving the combustion process. BSFC E20 values range from 420–350 g/kWh, slightly higher than Pertalite (400-330 g/kWh). This increase of 5-7% is acceptable, as it is still within the normal engine efficiency limits. This increase is a natural compensation for the lower calorific value of ethanol, offset by a more complete and stable combustion.

The use of E20 results in a lower exhaust gas temperature (around 20-30°C) than Pertalite over the entire load range. This shows that the heat from combustion is more used as mechanical energy, rather than wasted into the atmosphere. This phenomenon reinforces the evidence that E20 combustion is more efficient and controlled. From the results of exhaust gas testing using a gas analyzer, carbon monoxide (CO) levels decreased by 28-30%, and hydrocarbons (HC) decreased by about 20-25% with the use of E20 fuel. This shows

that ethanol as an oxygenate additive is able to improve combustion quality and reduce pollutant emissions. From a national energy perspective, the use of E20 contributes directly to energy diversification and reduced dependence on fossil fuels. Ethanol can be produced from local biomass sources such as sugarcane, cassava, and agricultural waste, thus opening up great opportunities for the development of the renewable energy bioindustry in Indonesia. The implementation of E20 also supports the green economy by creating a domestic bioethanol supply chain involving farmers and small and medium industries. This has a positive impact on sustainable development (SDGs 7 and 13**),** while reducing the deficit in fuel oil imports.

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Data Availability Statement

Derived data supporting the findings of this study are available from the corresponding author on request.

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