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Effect of ethanol–RON 92 (Pertamax) fuel blends on exhaust emissions of a 2000cc gasoline engine

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Abstract

The technology aimed at reducing dependence on fossil fuels and minimizing exhaust emissions involves the use of ethanol as an alternative fuel. This research investigates the effects of blending ethanol with RON 92 (Pertamax) gasoline on the exhaust emissions of a 2000cc four-cylinder gasoline engine. Experiments were conducted using varying ethanol concentrations, and the emissions of carbon monoxide (CO), hydrocarbons (HC), carbon dioxide (CO₂), and oxygen (O₂) were measured and analyzed. Data were presented descriptively and compared. The results indicate that adding ethanol significantly reduces CO and HC emissions. The lowest CO concentration (0.04%) was recorded with a 10% ethanol blend (BE10%), while the lowest HC emission (2316 ppm) occurred at a 15% ethanol blend (BE15%). Conversely, CO₂ emissions increased with ethanol content, peaking at 8.97% for BE15%. These findings demonstrate the potential of ethanol–gasoline blends to lower harmful emissions, particularly CO and HC, while enhancing combustion efficiency, as reflected by the increase in CO₂ levels.

Keywords:

Ethanol, gasoline engine, combustion, emissions

1 Introduction

The recent problem of fossil fuels presents a significant challenge in the transportation sector, particularly for motor vehicles that depend on fossil fuels, such as gasoline, as their primary energy source [1][2]. For several decades, fossil fuels have dominated the automotive industry due to their abundant availability and relatively low production costs [3-5]. However, with the increasing global demand and excessive exploitation, fossil fuel reserves are depleting, raising concerns about the sustainability of the energy supply for motor vehicles in the future. In addition to the threat of scarcity, the use of fossil fuels in motor vehicles significantly contributes to excessive exhaust emissions. These emissions are byproducts of fuel combustion in the engine, expelled through the exhaust system [6][7]. They occur when combustion in the chamber is incomplete. When gasoline burns, it reacts with Oxygen (O₂), producing gases such as Carbon Dioxide (CO₂), Carbon Monoxide (CO), and Hydrocarbons (HC) [8-10].

This condition promotes the exploration of alternative solutions to diminish reliance on fossil fuels and mitigate exhaust emissions from motor vehicles. One notable solution that has been developed and implemented in various countries is the use of ethanol as a fuel blend [11]. Ethanol, derived from biomass sources such as corn, sugarcane, or other plants, is a renewable fuel that can be sustainably replenished. The incorporation of ethanol as a fuel blend in motor vehicles, referred to as bioethanol, offers several significant advantages [12][13].

First, ethanol can reduce CO₂ emissions from motor vehicles, as its combustion is cleaner compared to conventional gasoline, making it a more environmentally friendly option in efforts to decrease greenhouse gas emissions. Second, ethanol possesses a higher octane rating than regular gasoline [14][15], which enhances combustion efficiency and the overall performance of motor vehicle engines. With an ethanol blend, engines can operate more optimally, generating greater power without increasing harmful pollutant emissions [16][17].

The increased adoption of ethanol as an alternative fuel in motor vehicles represents a crucial step in addressing the diminishing supply of fossil fuels. In addition to providing a solution to the challenge of excessive exhaust emissions, ethanol contributes to reducing dependence on fossil fuels and supports the transition to cleaner and more sustainable energy use in the transportation sector [18].

2 Methodology

The research experiment was conducted by testing a mixture of Pertamax and ethanol fuel on a 2.000 cc four-cylinder gasoline engine. The testing was carried out on an unloaded engine with varying engine speeds of 2000 rpm, 2500 rpm, 3000 rpm, and 3500 rpm, respectively. This research uses descriptive data analysis methods in graphical form, and then compares and analyzes exhaust gas emissions in terms of CO, HC, CO₂, and O₂ gases.

Fig. 1 illustrates the experimental setup utilized in this research. The image depicts the components of the engine and the gas analyzer employed to measure exhaust gas emissions. This study incorporates two variables: the independent variable, which consists of the engine speeds selected for data collection, specifically 2000 rpm, 2500 rpm, 3000 rpm, and 3500 rpm. Additionally, variations of fuel are used, including pure Pertamax (BE0%), 5% ethanol/95% Pertamax (BE5%), 10% ethanol/90% Pertamax (BE10%), and 15% ethanol/85% Pertamax (BE15%). The dependent variable encompasses the exhaust gas emissions, specifically the carbon gases CO, HC, and CO₂, as well as the fuel consumption.

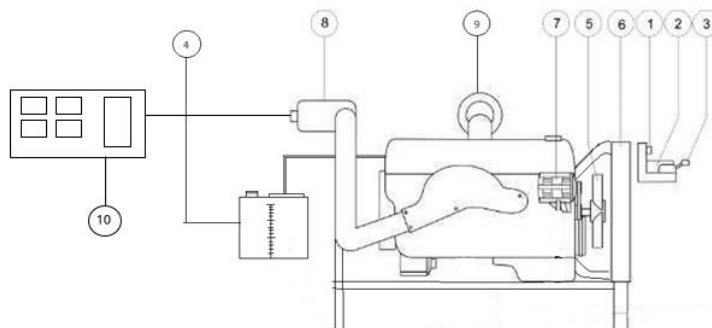


Fig. 1. Experimental setup

Description in Fig. are, 1. Starting engine, 2. Speedometer, 3. Throttle control, 4. Fuel tank, 5. Radiator fan, 6. Radiator, 7. Alternator, 8. Exhaust, 9. Air filter, and 10. Gas analyzer. The specification of the experimental engine can be seen in Table 1.

Table 1. The specification of the experimental engine

Items		
Engine type		4 cylinders, 16 Valve, DOHC, VVT-I
Displacement		1,998
Bore Diameter		86
Stroke		86
Power		136 PS / 5,600 rpm
Torque		18.6 Kgm / 4000 rpm
Fuel	Type	Gasoline
	System	Fuel Injection (EFI)

This test is conducted in a 4-cylinder 2000 cc gasoline engine as shown in Table 1. The process of testing exhaust gas emissions is carried out by channeling some of the exhaust gas from the engine's exhaust. The exhaust gas is channelled using an iron pipe connected with a heat-resistant hose to convey the exhaust gas, which will later

be tested for its emission values. The process of collecting exhaust gas emission data will be carried out using the HESHBON HG-520 emission or gas analyzer. This tool is guaranteed to detect the gas content in the engine, such as CO₂, CO, and HC. The specification of gas analyzer is shown in Table 2.

Table 2. Gas analyzer Heshbon HG-520

Items	
Brand	Heshbon
Type	HG-520
CO measurement	0-9.99% with 0.01% resolution
HC measurement	0-9999 ppm / 1 ppm resolution
CO ₂ measurement	0-20.00% with 0.01% resolution
O ₂ measurement	0-25.00% with 0.01% resolution
Lamda range	0-2.000 with 0.01% resolution

3 Results and discussions

Data on emissions from the combustion of the tested diesel engine will be collected. The exhaust gas emissions, in the form of smoke, will pass through a probe with small openings that facilitate the transfer of smoke from the exhaust pipe to the gas analyzer. This process must be conducted with calibration of the gas analyzer, which involves automatically purging or venting the gas analyzer for approximately 40 seconds.

3.1.1 The octane number of the mixture of fuel

Before conducting the exhaust gas emission test. First, the fuel to be tested, namely Pertamina and ethanol, is mixed (Fig. 2). Each of these fuels has an RON of 92 for Pertamina and RON 128 for ethanol in a 1-liter test, with the volume of the fuel mixture can be seen in Table 3.

Table 3. Volume of the mixture of fuel

No	Mixed Fuel	Pertamax (ml)	Ethanol (ml)
1	BE5	950	50
2	BE10	900	100
3	BE15	850	150



Fig. 2. Mixture fuel

The octane number measures a fuel's resistance to knocking in internal combustion engines, particularly in gasoline engines. Knocking occurs when the fuel-air mixture in the engine cylinder ignites uncontrollably, leading to vibrations and noise that can damage the engine. A higher octane number indicates a fuel's greater ability to prevent knocking. Knocking, or detonation, occurs when pressure and temperature in the combustion chamber suddenly rise, causing the air-fuel mixture to ignite abruptly. Fuels with a higher-octane rating are typically used in engines with higher compression ratios, which require more stable fuel to avoid knocking. The octane rating of Pertamina is 92, while that of ethanol is 117. When mixed, the resulting octane number is illustrated in Fig. 3.

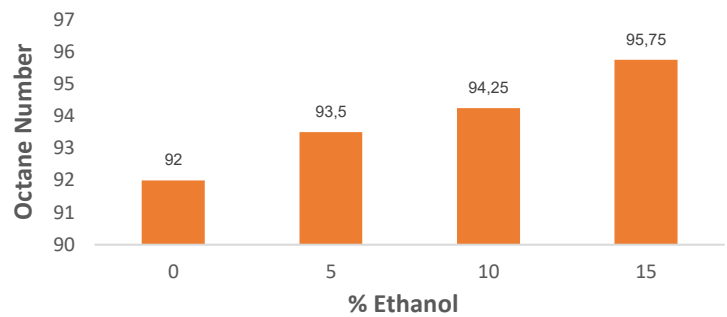


Fig. 3. Octane number

From Fig. 3, it can be seen that the higher the ethanol content in the fuel mixture, the higher the octane number will be. The higher the octane number in the fuel, the more compression the fuel can withstand before an explosion occurs in the combustion chamber. When the fuel is compressed in the piston, the pressure will rise, making it easier for the fuel to ignite before reaching TDC. Fuel with a lower octane number is prone to knocking due to the collision between the explosion of fuel that detonates without a spark plug and the fuel ignited by the spark plug.

3.1.2 Analysis of CO emission

Exhaust gas emissions of CO can indicate the efficiency of combustion occurring in the combustion chamber. The data presented below show the exhaust gas emission values, specifically for CO, at various engine speeds. At 2000 rpm with pure Pertamina fuel, CO emissions were measured at 1.61%. At 2500 rpm, a micro-explosion occurred due to the breakup of fuel droplets, which enhanced the mixing of fuel with air, resulting in a more homogeneous mixture. This phenomenon led to a momentary explosion, resulting in the highest emission value of 1.84% at 2500 rpm with pure Pertamina fuel (BE0%). At 3000 rpm, CO emissions decreased significantly to 1.31%, but at 3500 rpm, the CO value increased again to 1.37%. The lowest CO emissions were observed at 3500 rpm with BE10% fuel, which recorded a CO value of 0.4%. This finding indicates that the reduction of CO compounds occurs with the addition of ethanol to gasoline.

Notably, CO emissions from the engine at 2000 rpm using pure Pertamina decreased from 1.61% to 1.32% with the addition of BE5%, a reduction of 0.29%. The BE10% fuel led to a further significant reduction of 0.93%. Adding BE15% fuel at 2000 rpm resulted in a negligible reduction of only 0.4%. The most substantial decrease in CO emissions occurred with the BE10% fuel mixture at 2500 rpm, where emissions dropped from 1.65% with BE5% to 0.17%. However, the ideal result was achieved with the BE10% fuel mixture at 3500 rpm, producing the lowest CO emissions of 0.04%. The result of percentage can be seen in Fig. 4.

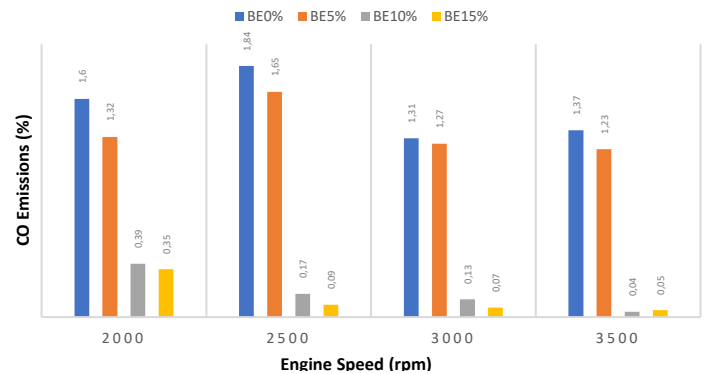


Fig. 4. CO emissions

3.1.3 Analysis of HC emissions

The data in Fig. 5 shows the exhaust gas emission value, especially HC gas, which has different values at each engine speed. HC emissions occur due to unburned fuel expelled along with exhaust gases caused by incomplete combustion. HC indicates the leftover fuel that is wasted along with the exhaust smoke. In the HC

exhaust gas emission data, there is an increase at each rpm. Starting from 2000 rpm to 3500 rpm with pure Pertamax fuel BE0%, the results obtained were consecutively 2732 ppm, 3077 ppm, 3140 ppm, and 3561 ppm. Meanwhile, with BE5% fuel, a decrease in HC emission levels was observed, as seen in Fig. 5, where from 2000 rpm to 3500 rpm, a decrease in HC of 2616 ppm, 2922 ppm, 2998 ppm, and 3266 ppm was obtained. The reduction in HC gas emissions also occurs with BE10% fuel, as can be seen in Fig. 5. The overall reduction in emissions with BE10% fuel from 2000 rpm to 3500 rpm, in succession, is 2327 ppm, 2399 ppm, 2377 ppm, and 2456 ppm. From the graph comparing hydrocarbon levels in Fig. 5, it can be seen that the HC levels in a 2000cc gasoline engine with pure Pertamax fuel are higher compared to ethanol-blended fuel. The high HC emissions in Pertamax can be attributed to the higher carbon atom value in Pertamax compared to the carbon atom value in ethanol, so during the combustion process, the hydrocarbon emissions from Pertamax are higher. The smaller the HC value, the better the combustion that occurs in the combustion chamber because the fuel does not go to waste along with the exhaust gases.

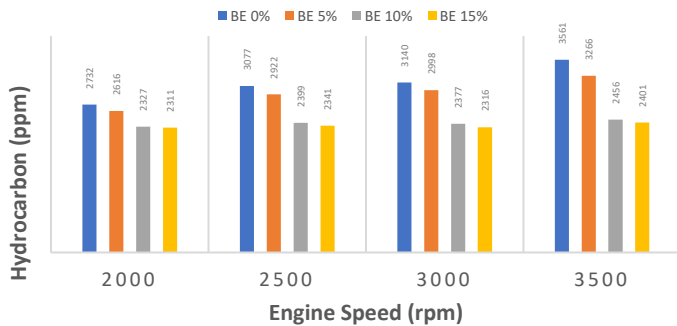


Fig. 5. HC emissions

3.1.4 Analysis of CO₂ emissions

The data in Fig.6 shows that the exhaust gas emissions indicate varying levels of CO₂ across different engine speeds. CO₂ is a byproduct of the complete combustion of motor vehicle fuel, and higher CO₂ concentrations suggest more efficient combustion within the engine [19]. As shown in Fig. 6, CO₂ emissions in this study increased with the use of pure Pertamax fuel (BE0%), recording values of 6.70%, 7.10%, and 7.70% at various speeds, before decreasing to 7.50% at 3500 rpm. This reduction in CO₂ content during combustion may result from several factors that suggest suboptimal fuel combustion, such as insufficient oxygen in the combustion chamber. This phenomenon warrants further investigation [20] that with a high percentage of ethanol in the fuel mixture, the CO₂ emission is increased. In BE5% fuel with engine speeds of 2000 to 3500 rpm, there was an increase in CO₂ emissions, respectively, 6.90%, 7.5%, 7.83%, and 7.86%.

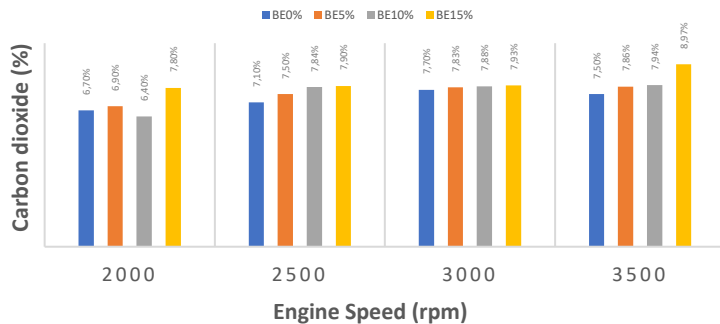


Fig. 6. CO₂ emissions

3.1.5 Analysis of O₂ emissions

The data in Fig. 7 shows the value of exhaust gas emissions, which is in the form of O₂ gas that has different values at each engine speed. O₂ is the gas used to assist in the combustion process within the engine. The more oxygen used, the more efficient the combustion that occurs. But if oxygen is wasted, it will result in decreased engine performance or incomplete combustion. It can be seen in Fig. 7, the O₂ emissions in this study increased with pure Pertamax fuel BE0%

at 2000 to 3500 rpm, producing O₂ gas emission levels of 11.11%, 10.37%, 9.65%, and 9.69%. The lowest O₂ level occurred at 3500 rpm with BE15% fuel, which was 8.8%. This can serve as a reference that the addition of ethanol to Pertamax fuel can reduce O₂ emissions and indicates that the combustion occurring in the combustion chamber is better compared to pure Pertamax.

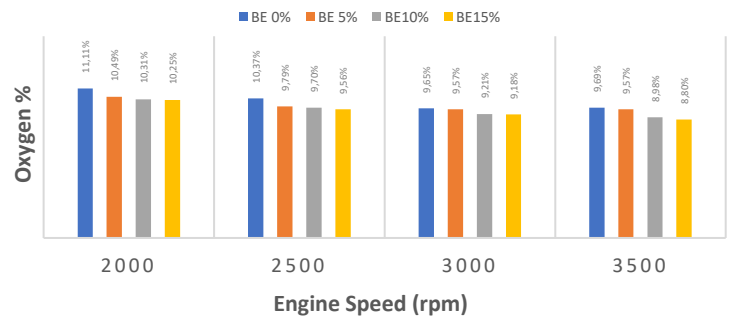


Fig. 7. O₂ emissions

3.1.6 Analysis of air-fuel ratio

The data obtained pertains to the Air-Fuel Ratio (AFR), which represents the ratio of air to gasoline fuel entering the engine's combustion chamber. Theoretically, stoichiometric theory posits that the ideal AFR is 14.7:1, meaning that 14.7 grams of air are required to completely combust 1 gram of gasoline. However, in practice, the AFR often deviates from this theoretical value due to the engine operating under varying loads and conditions.

As illustrated in Fig. 8, the results of the AFR under BE0% conditions demonstrate a decrease at each engine speed, reaching a minimum value of 22.9 at 3500 rpm. The ideal AFR is 14.7, indicating that under BE0% conditions, there is significant fuel wastage along with the exhaust gases, commonly referred to as a rich mixture. This occurs because, at higher speeds, the fuel consumption increases, and the engine struggles to combust all the fuel, leading to substantial fuel wastage or knocking at elevated speeds. Under BE15% conditions, the AFR exhibits a pronounced decrease, reaching a minimum of 19.6. This change is attributable to bioethanol's higher oxygen content and octane number, which optimize the combustion process, thereby enhancing efficiency and reducing fuel wastage. As the ethanol content in the fuel rises, the stoichiometric AFR value adjusts accordingly. The actual AFR is modified to approach the ideal (stoichiometric) AFR, enabling the combustion process to approach its theoretical efficiency. To determine the stoichiometric AFR value based on the gasohol content, it can be calculated using the chemical reaction equation in Eq. (1).

$$AFR_{stoichiometri} = \frac{N_{air} M_{air}}{N_{fuel} M_{fuel}} \quad (1)$$

where N_{air} is the number of moles of air, M_{air} is the mass of air based on mole, N_{fuel} is the number of moles of fuel, and M_{fuel} is the mass of fuel based on mole.

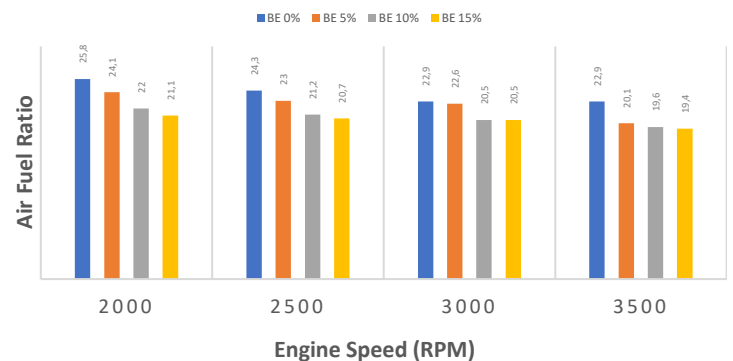


Fig. 8. Air-fuel ratio

3.1.7 Temperature of exhaust gas

In this study, the measurement of exhaust gas temperature was conducted using a thermocouple installed in the exhaust duct. The

data from this thermocouple is used to determine the exhaust gas temperature emitted by the engine at various engine speeds. The exhaust gas temperature in gasoline engines is an important parameter that provides information about the combustion condition and engine performance. The following are the data that include the exhaust gas temperature of the engine in this study, which will be described in Fig. 9.

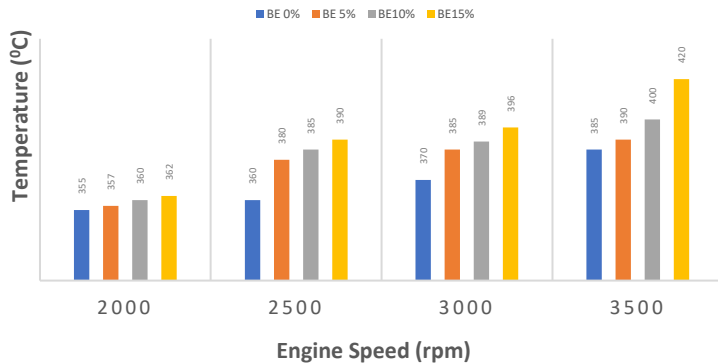


Fig. 9. Exhaust gas temperature

The relationship between exhaust gas temperature and engine performance is a crucial indicator of the engine's efficiency and operating condition. A high exhaust gas temperature suggests efficient combustion, as the heat energy from fuel combustion is not fully absorbed by the piston and other components, leading most of it to exit through the exhaust [8]. In contrast, a low exhaust gas temperature may indicate incomplete combustion, where the energy from the fuel is not maximally utilized, resulting in decreased engine efficiency [21].

The graph above illustrates that the exhaust gas temperature of the engine increases with rising RPM, from a low of 2000 RPM to 3500 RPM. Notably, the PE15% fuel achieves the highest temperatures at each engine rotation, with recorded values of 362°C, 390°C, 396°C, and 420°C for RPMs of 2000, 2500, 3000, and 3500, respectively. This suggests that the addition of ethanol can enhance the exhaust gas temperature of the engine. However, excessively high exhaust gas temperatures may damage engine components, such as the exhaust valve and manifold, and can lead to cracking in metal components.

4 Conclusions

The experimental tests on exhaust gas emissions were conducted using variations of pure RON 92 (Pertamax) and a mixture of Pertamax and ethanol in a 2000 cc four-cylinder gasoline engine (1TR-FE). The following conclusions were drawn:

1. The most significant reduction in CO emissions occurred with the BE10% fuel mixture, where the exhaust gas emissions decreased to 0.04% compared to pure Pertamax fuel.
2. The most significant reduction in HC emissions occurred with the BE15% fuel mixture, where the exhaust gas emissions decreased to 2316 ppm compared to pure Pertamax fuel (BE0%).
3. The addition of ethanol in this study can increase CO₂ levels. The most significant increase in CO₂ emissions occurred with the BE15% fuel mixture, where the CO₂ content increased to 8.97% compared to pure Pertamax fuel (BE0%).

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