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THE EFFECT OF FUEL INJECTION DURATION ON EXHAUST GAS EMISSIONS OF A 4-STROKE ENGINE 113.68 CC USING BIOETHANOL FUEL

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Abstract

In Indonesia, the number of motor vehicles using fuel as an energy source is rising quickly. The government has developed renewable energy to reduce fuel consumption because, according to the Downstream Oil and Gas Regulatory Agency (BPH Migas), the consumption of gasoline-type fuels in 2017 was 1,858,875 L/Quarter. Determining the impact of using bioethanol with different injection times on exhaust gas emissions was the aim of this study. Bioethanol is an environmentally friendly alternative fuel for cars that uses less fuel. It is a renewable energy source made from vegetable sources. Variations in fuel injection duration and exhaust gas emission are the main subjects of this study. With no modifications to compression, the engine operates under standard conditions. A gas analyzer and engine speeds of 1500, 2000, 3000, 4000, and 5000 Rpm were used in the study. According to the study's findings, the amount of CO exhaust gas dropped. At 5000 RPM for 4 ms, the lowest CO in bioethanol fuel is 1.21%. With bioethanol fuel, the amount of HC exhaust gas emissions has dropped. 710 ppm at 3000 Rpm for 4 ms is the lowest HC level. When using bioethanol as fuel, the amount of CO2 emissions rises. The maximum CO2 concentration is 6.50% at 5000 RPM for 4 ms. The maximum amount of O2 emissions from bioethanol fuel is recorded at 1500 RPM for 4 ms.

Keywords : bioethanol, injection duration, exhaust emissions

INTRODUCTION

Indonesia's growing population has led to an annual increase in the country's need for fuel oil. The Downstream Oil and Gas Regulatory Agency (BPH Migas) estimates that 75 million kiloliters (KL) of fuel oil (BBM) were used in 2018. The government has created renewable energy sources in response to the rising demand for fuel oil in an attempt to reduce its consumption. Every year, the government strives to increase the use of renewable energy sources and bioethanol; in 2010, the five percent goal was achieved. 35 to 42 million liters of bioethanol are planned annually as an alternative fuel for renewable energy. If alternative fuel is used for complete manufacturing, that figure will rise to 81 million liters annually (Kholiq, 2015).

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start the engine under typical conditions utilizing bioethanol needs, the injection duration must be extended to satisfy the engine's AFR. The researcher added an Arduino-based fuel controller to increase the duration of fuel injection.

The ECU's signal output is manipulated by the fuel controller. Instead of being sent straight to the injector, the signal from the ECU is reset by the fuel controller using commands from the Arduino.

- **Exhaust Emissions**

The combustion residue from internal combustion engines is the source of exhaust pollutants, which contribute to air pollution. This results from incomplete combustion in the combustion chamber, which releases exhaust particles into the environment. When carbon and hydrogen burn completely, they are converted to CO2 and H2O.

Winoko et al. (2018), combustion is not always flawless and can result in the production of harmful pollutants such hydrocarbons (HC) and carbon monoxide (CO). ccording to Erwin (2006), motor vehicle-generated air pollution accounts for 70% of all pollutants. It is composed of 99% CO gas, 89% HC gas, 73% NOx gas, and various exhaust gas emission particles such dust, lead, and sulfur oxides.

The "HESHBON HG-520" exhaust emission tester was employed in this investigation. The motorcycle engine was warmed to operating temperature and the exhaust emission tester's filter and probe were cleaned prior to the test in order to obtain accurate emission readings.

Figure 1. Exhaust Gas Emissions Tool

- **Bioetanol**

Bioethanol, or ethyl alcohol (ethanol), uses sugar as the raw material derived from biomass sources (plants) through biological processes (enzymatic and fermentation). Bioethanol raw materials can include starchy materials such as cassava, corn kernels, etc., sugary materials such as nipa palm sap, molasses, sugarcane sap, coconut sap, etc., and cellulosic materials using agricultural waste.

- **Characteristics of Gasoline and Bioethanol**

The table below explains the characteristics of gasoline and E100 bioethanol fuel.

Table 1. Caracteristics of Gasoline and Bioetanol

Property	Gasoline	Bioetanol
Chemical formula	C8-H11	C2H5OH
Molar mass (g/mol)	102.5	46.07
C (%wt)	86.5	52.2
H (%wt)	13.5	13.1
O (%wt)	0	34.7
Density (kg/m3)	740	794
Research octane number (RON)	92	109-120
Flash point (°C)	-42s/d-13	13
Boiling point at 1 bar (°C)	25-215	79
Lower heating value (MJ/kg)	42.9	26.95
Latent heat of vaporization (kJ/kg)	289	854
Stoichiometric ratio	14.7	9
Laminar flame speed (m/s)	0.28	0.40
Flame temperature (λ = 1)[°C]	2290	1930

- **Fuel Controller**

Fuel controller in this study completely regulates the injection time in response to commands from the Arduino. Its basic function is to control the signal that is sent from the ECU to the injector.

Fuel controller receives the signal from ECU and then response to orders from the Arduino reconfigures it to produce the desired output. The injector is subsequently instructed to spray fuel into the combustion chamber via fuel controller ouput.

The primary objective of this study was to evaluate the impact of varying fuel injection durations on the exhaust emission characteristics of a 113.68 cc four-stroke motorcycle engine. Utilizing E100 bioethanol as the primary fuel source, the research analyzed the fluctuations in Carbon Monoxide (CO), Hydrocarbons (HC), Carbon Dioxide CO_2, and Oxygen (O_2) levels across a standardized range of engine speeds from 1,500 to 5,000 rpm. By maintaining a stock engine configuration, this investigation sought to identify the optimal injection mapping required to maximize combustion efficiency and minimize environmental pollutants, providing empirical data on the performance of oxygenated biofuels in small-displacement internal combustion engines.

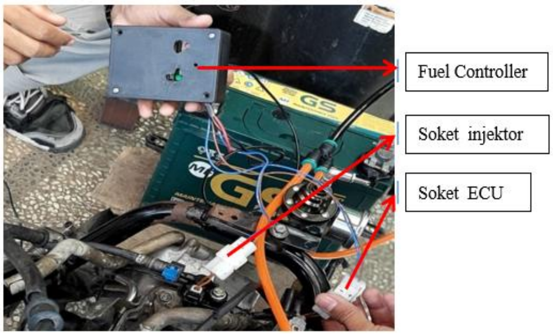

Figure 2. Fuel Controller

METHOD

This research employed an experimental methodology utilizing a standard 113.68 cc motorcycle engine to evaluate the impact of varying fuel injection durations on exhaust emissions, specifically focusing on E100 bioethanol. By standard compression ratio without mechanical modifications, the study isolated the influence of electronic fuel injection (EFI) parameters on combustion quality. Following the principles outlined by Heywood (2018) regarding internal combustion engine fundamentals and drawing upon the bioethanol emission frameworks established by Mulyono and Syarifudin (2018) and Balki et al. (2014), the experiments were conducted across a speed range of 1,500 to 5,000 rpm.

The results confirm that CO emissions are highly sensitive to injection timing; a 4ms duration proved optimal, achieving a minimum CO level of 1.21% at 5,000 rpm. In contrast, durations of 3.5ms and 4.5ms led to significantly higher emissions due to lean-burn instability and fuel-rich incomplete combustion, respectively. Ultimately, the data indicates that higher engine speeds facilitate superior air-fuel homogenization through increased intake turbulence, thereby mitigating the carbon monoxide output inherent at lower operational speeds.

Table 2. Tools and Materials

Tools	Materials
Gas Analyzer	Bioetanol 95%
Tachometer	Pertalite RON 88
Fuel Controller	
Pressure Regulator	
Pressure Gauge	
Arduino nano	
Optocopler	
Diode	

Specifications

The engine used for this research is a 4-stroke gasoline engine with an injection system with a capacity of 113.68 cc with engine specifications are listed in the table 3.

Table 3. Engine Spesification

Engine Type	4 Stroke 4 Valve SOHC Fuel Injection
Diameter x Stroke	50.0 x 7.9mm
Cylinder Volume	113.7 cc
Cylinder Arrangement	Single Cylinder/ upright
Maximum Power	7.75 PS at 8500 rpm
Maximum Torque	8.5 N.m at 5000 rpm
Lubrication System	Wet
Engine Oil	Total 0.85 Liters
Clutch	Dry, Centrifugal Automatic Type
Transmission System	Automatic V-belt
Starter System	Electric Starter and Kick Starter

Research methods

In this research, a 113.68 cc motorcycle was used for the experiments. Standard compression was used for the experiments; no modifications were made.

E100 bioethanol-derived vehicle exhaust emissions were the study's main focus. This study's initial hypothesis was that ethanol-fueled vehicles at engine speeds of 1500, 2000, 3000, 4000, and 5000 rpm would be affected by different fuel injection durations.

RESULT AND DISCUSSION

In this discussion, a graph of the test results using E100 bioethanol and Pertalite.

CO Emission Test Result

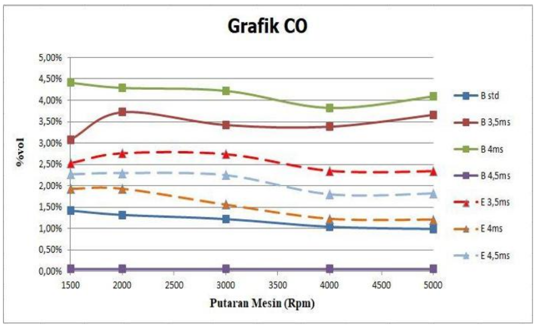

Figure 3. CO Emission Test

The graph above shows a clear non-linear relationship between injection duration and combustion efficiency, where a 4ms duration represents the stoichiometric "sweet spot" for bioethanol, yielding the lowest CO emissions (1.21%–1.45%). Deviating from this midpoint causes a sharp increase in pollutants: a shorter duration (3.5ms) likely induces a lean-burn limit resulting in incomplete flame propagation, while a longer duration (4.5ms) creates an over-rich mixture where insufficient oxygen prevents the full oxidation of Carbon into CO. The consistent reduction of CO levels at 5,000 rpm across all test groups underscores the role of mechanical turbulence; higher engine speeds enhance the atomization and mixing of the bioethanol, compensating for the fuel's high latent heat of vaporization and ensuring more complete combustion compared to the lower air velocities found at 1,500–2,000 rpm.

Bioethanol fuel with injection durations of 3.5ms and 4ms has high CO levels, due to the large volume of fuel entering but little air entering the combustion chamber. This results in an incomplete reaction of carbon and oxygen, forming CO.

HC Emission Test Result

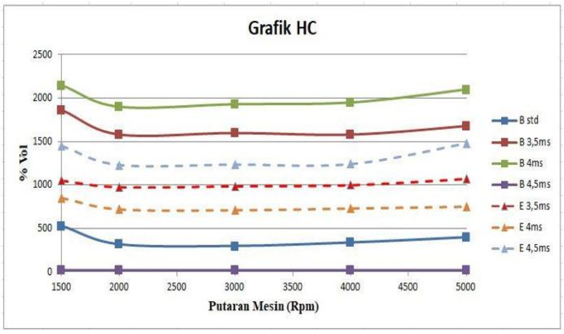

Figure 4. HC Emission Test

The graph above shows that Hydrocarbon (HC) emissions in an E100 bioethanol-fueled 113.68 cc engine are significantly influenced by the interplay between injection duration and rotational speed, with the 4ms duration achieving the most efficient combustion profile at a minimum of 710 ppm at 3,000 rpm. The marked increase in HC levels at durations of

3.5ms and 4.5ms—reaching peaks of 1,070 ppm and 1,480 ppm at 5,000 rpm, respectively—indicates that deviations from the optimal fuel pulse lead to incomplete combustion and the expulsion of unburned fuel. These elevated emissions are primarily attributed to the engine's standard compression ratio, which, as noted by Heywood (2018), provides insufficient thermal energy and pressure to fully oxidize the bioethanol under high-volume injection or improper ignition timing conditions. Consequently, the findings suggest that without increasing the compression ratio or optimizing ignition mapping, varying the injection duration alone results in excessive HC discharge due to the difficulty of fully burning bioethanol in a standart mechanical configuration.

CO_2 Emission Test Result

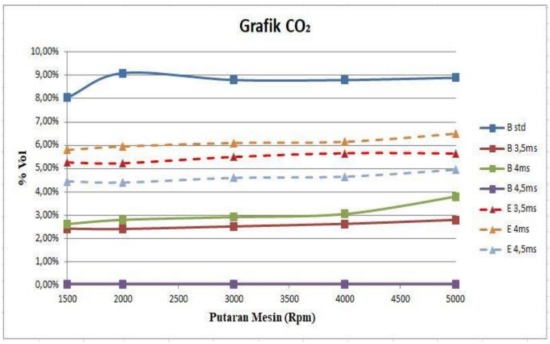

Figure 5. CO_2 Emission Test

The graph above shows that Carbon Dioxide (CO_2) emissions indicate a direct correlation between combustion efficiency and the concentration of exhaust gases in an E100 bioethanol-fueled 113.68 cc engine. The data identifies the 4ms injection duration as the most effective setting for maximizing fuel oxidation, reaching a peak CO_2 level of 6.50% at 5,000 rpm. This trend is significant because, in internal combustion engines, higher CO_2 output serves as a primary indicator of complete combustion, signaling that the carbon in the fuel is being fully oxidized rather than being wasted as CO or unburned HC. In contrast, the 3.5ms and 4.5ms injection durations yielded substantially lower CO_2 concentrations, with minimums of 5.23% and 4.40% at 2,000 rpm, and maximums failing to exceed 5.66%. These lower (CO_2) levels at 3.5ms and 4.5ms suggest a degraded air-fuel homogeneity and an inadequate equivalence ratio, where the mixture is either too lean or too rich to support an efficient burning. Consequently, while the 4ms setting optimizes the chemical energy release from the bioethanol, the outlying durations result in poor thermal efficiency due to the engine's standard compression constraints, which prevent the complete conversion of reactants into CO_2 as described in the combustion frameworks of Heywood (2018) and Balki et al. (2014).

O_2 Emission Test Result

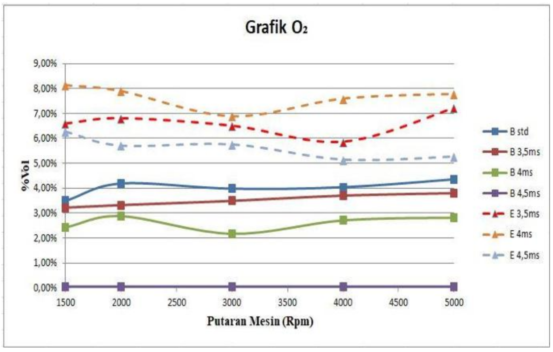

Figure 6. O_2 Emission Test

The graph above results indicate that the 4ms injection duration maximizes oxygen (O_2) concentrations in the exhaust, peaking at 8.14% at 5,000 rpm, whereas durations of 3.5ms and 4.5ms yielded significantly lower maximums of 7.22% and 6.27%, respectively. This higher O_2 content in bioethanol-fueled cycles, compared to standard gasoline, is primarily attributed to the fuel's molecular structure (C_2H_5OH) and its inherent oxygenated nature. As highlighted by Balki et al. (2014), bioethanol's higher oxygen weight and potential trace water content facilitate increased oxygen availability during the combustion process. The reduction in O_2 levels at 3.5ms and 4.5ms suggests an inefficient equivalence ratio that fails to utilize the fuel's oxygenated properties as effectively as the optimal 4ms setting, which maintains a superior oxygen surplus for oxidation, particularly at high engine speeds.

CONCLUSION

Based on the results of the research that has been conducted, it can be concluded that;

- On a 113.68cc standard compression motorcycle, bioethanol cannot be fueled due to its relatively low AFR compared to gasoline. Therefore, it is necessary to increase the injection duration to approach the AFR value so the motorcycle can start and be used.
- Increasing the injection duration by 1ms on a 113.68cc bioethanol-fueled vehicle is considered the most appropriate for vehicles with standard conditions. However, it cannot be better than using gasoline fuel, especially in terms of CO and HC content because the engine still has standard compression conditions.

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