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Utilization of Biopertalite for Fuel Efficiency and Reduction in CO and CO_2 Gas Emissions in Four-Wheel Motor Vehicles

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Abstract

Emissions of carbon monoxide (CO) and carbon dioxide (CO_2) gases are the main problem that must be rectified as they are harmful and contribute to global warming through the greenhouse gas effect. In Indonesia, motor vehicles, especially four-wheelers, are one of the biggest contributors with up to 71 million tons of CO_2 emissions and energy consumption of 179 million barrel of oil equivalent. Bioethanol has octane rating >100, which is higher than that of gasoline; and emission contribution of only 0.02 kg/L, which is lower than that from gasoline (2.23 kg/L). Accordingly, a mixture of gasoline and bioethanol is the solution proposed in this study to solve the issues of CO and CO_2 emissions. Gasoline and bioethanol mixture consists of six products, namely E-0, E-5, E-10, E-15, E-20, and E-25, which have different percentage values of bioethanol mixture (0%–25%). This study was conducted through engine testing with different rpm values (500–2500 rpm) to identify the concentration and mass of CO_2 emissions, fuel efficiency, and cost efficiency. Based on the test results, this product succeeded in reducing CO emissions by up to 86% and CO_2 emissions up to 30.6% from Pertalite (E-0) and increasing the fuel efficiency up to 51.76% for 1 L and cost efficiency up to 33.6% after considering the actual price of Pertalite. Therefore, the proposed product can be a solution to the existing problems.

Keywords: bioethanol, biopertalite, emission, fuel efficiency, greenhouse gases, motor vehicles

1. Introduction

General background. Based on the data obtained from the Ministry of Energy and Mineral Resources of the Republic of Indonesia in January 2021, oil and gas reserves in Indonesia are increasingly limited. Hence, oil reserves will only last about 9.5 years, and natural gas reserves will only last around 19.5 years, if no new sources are discovered. Meanwhile, population in Indonesia continues to increase and it causes an increase in the number of private vehicle ownership. The comfort level of using private vehicles has also increased in line with the case of the COVID-19 pandemic. Figure 1 illustrates the number of motorized vehicles in Indonesia in 2018–2020 according to the Central Statistics Agency (BPS) [1].

As shown in Figure 1, the number of motorized vehicles reached ±136 million units in 2020. 96% of these motorized vehicles are private vehicles. This phenomenon causes an increase in the number of private vehicles that are not equivalent to the availability of existing roads, especially in urban areas. This condition not only causes traffic jams but also increases carbon emissions, which are one of the sources of environmental pollution. For this reason, the government has taken steps to build the Trans-Java Toll Road and Trans-Sumatra Toll Road to overcome this problem [2].

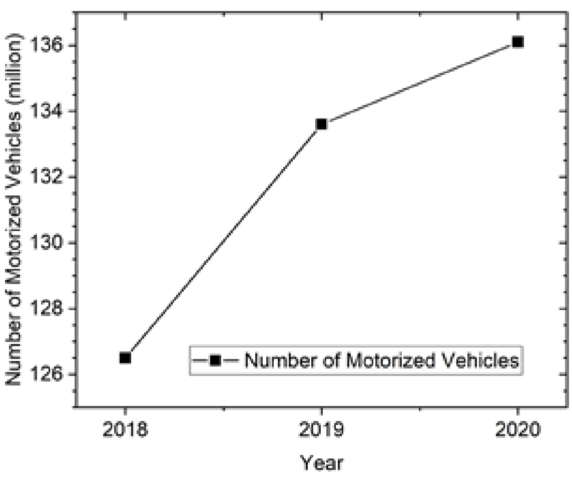

Figure 1. Motorized Vehicle Increase in 2018–2020

Nonetheless, the pollution from vehicle exhaust emissions has the potential to increase because the frequency of motorized vehicle mobility can increase with the existence of toll road facilities.

Air consists of three main elements, namely, dry air, water vapor, and aerosols. The content of dry air is 78.6% nitrogen, 20.9% oxygen, 0.093% argon, 0.04% carbon dioxide (CO_2), and 0.06% other gases [3]. The focus is on air pollution problems and significant exhaust gas emissions from motor vehicles, namely, carbon monoxide (CO) and CO_2 gas emissions. CO gas is toxic and harmful to human health, while CO_2 gas has a greenhouse gas effect that contributes to global warming.

This study has two objectives: first, to reduce the consumption of fossil fuels and, second, to reduce the exhaust emissions of CO and CO_2 gases using alternative fuels of bioethanol as a mixture of Pertalite [4].

Bioethanol can reduce CO_2 emissions by 30%–70%, while second-generation bioethanol can reduce CO_2 emissions by up to 90% [5]. Moreover, bioethanol is a renewable fuel that has the potential to reduce gas pollutions because bioethanol produce fewer emissions of particulates, sulfure dioxide, and air toxics than fossil fuel [6-7].

The characteristic comparison between ethanol and gasoline is shown in Table 1 [8].

Biofuels are among the new renewable energies that derive from processing biomass. Biofuels are also often called green energy because their origins and emissions are environmentally friendly and do not cause significant global warming. Commonly used biofuels today are biodiesel and bioethanol [9]. Bioethanol has octane rating >100, higher than that of gasoline [10]. In this research, the mixture of bioethanol, which is an alternative fuel and renewable energy source, and Pertalite (Indonesia's fuel product) in a certain composition and volume, named Biopertalite is used to solve the issues of CO_2 and CO emissions [10]. The amount of ethanol and its impact on the efficiency of Biopertalite fuel, CO_2 and CO emissions, and cost efficiency was investigated by using automotive emission analyzer. In addition, Biopertalite is expected to reduce the dependencies of the people of Indonesia on the existing fuel products including Pertalite that has higher prices.

Table 1. Comparison of Physical and Chemical Characteristics between Ethanol and Gasoline

No.	Characteristics	Ethanol	Gasoline
1	Molecular Weight	46.07	100–105
2	C, Carbon (wt %)	52.2	85–88
3	H, Hydrogen (wt %)	13.1	Dec-15
4	O, Oxygen (wt %)	34.7	2.7
5	Density (15 °C), (kg/L)	0.79	0.72–0.77
6	Boiling Point (°C)	78	27–225
7	Vapor Pressure (38 °C), kPa	15.9	48–103
8	Viscosity (20 °C), (mPa s)	1.19	0.37–0.44
9	Autoignition Temperature (°C)	423	257
10	Octane Number	112.5–114	85–94

Based on the above explanation, several problem formulations will be discussed in this paper, including the amount of CO and CO_2 emissions from the test machine before and after using Biopertalite, effect of Biopertalite on CO and CO_2 gas emissions from the test machine experiment, effect of using Biopertalite products on greenhouse gas emissions, distance from the test machine before and after using Biopertalite, and effect of using Biopertalite products on the fuel efficiency.

Objectives. The following are the objectives of this study: 1) Investigating the role of Biopertalite products in reducing air pollution; 2) Reduce environmental pollution that has a direct impact on the community, especially CO and CO_2 gas emissions; 3) Investigating the potential fuel efficiency of Biopertalite products in machines/motorcycles that will be implemented in the industrial world.

2. Methods

Tools and materials. The equipment used in this study include a test engine, a 1994 Suzuki Carry/ST100 minibus with a cylinder volume of 970 cc, a QROTECH automotive emission analyzer (QRO-402) to measure CO and CO_2 emissions in a test machine, a stopwatch to measure time, a tachometer to determine the number of revolutions per minute of vehicle engine, a measuring cup to measure the ratio of the bioethanol mixture to be tested when mixed with Pertalite, and an alcohol meter to measure the water content in bioethanol fuel.

The materials used in this research are Pertalite fuel and 99.9% bioethanol (fuel grade) with percentages of a mixture of Pertalite and bioethanol of 0%, 5%, 10%, 15%, 20%, and 25%, whose details are as follows:

1. E-0 (100% Pertalite).
2. E-5 (95% Pertalite + 5% bioethanol in 1 L mixture).
3. E-10 (90% Pertalite + 10% bioethanol in 1 L mixture).
4. E-15 (85% Pertalite + 15% bioethanol in 1 L mixture).
5. E-20 (80% Pertalite + 20% bioethanol in 1 L mixture).
6. E-25 (75% Pertalite + 25% bioethanol in 1 L mixture).

Research steps. The exhaust emission tests carried out include measuring CO and CO_2 levels from fuel combustion. The test was performed using the QROTECH QRO-402 automotive emission analyzer. In the test, variations in rotation were carried out, which include variations in rotations of 500, 1000, 1500, 2000, and 2500 rpm. The emission testing step was conducted when the car is in a standard condition or ready to be tested and when the car is given a mixture of Pertalite and Bioethanol, E-0, E-5, E-10, E-15, E-20, and E-25 fuel. The gas emission testing workflow is shown in **Error! Reference source not found.**.

After the test, a comparison of the emitted CO and CO_2 gas concentrations was then performed. The emission test using the emission analyzer was performed in accordance with the procedures of the Minister of Environment Regulation No. 5 of 2006 using SNI 19-7118.1-2005 regarding vehicle emission test procedures.

Research variables. The research comprises the following variables:

Control. The control in this study include the type of fuel used: Pertalite, 1 L fuel volume, and maximum vehicle speed of 40 km/h. Fuel efficiency testing was performed on public roads/highways in Semarang. No power or acceleration tests were carried out on the test machine. The test was repeated three times, and the average result was taken. The results of this efficiency test provide the distance traveled in kilometers.

Independent variables. The independent variables in this study include variations in the engine speed (rpm) at the time of the emission test according to SNI 19-7118.1-2005 and variations in the percentage of bioethanol mixed with the Pertalite;variations in rotation rates used for emission measurements are 500, 1000, 1500, 2000, and 2500 rpm and concentrations of bioethanol in Pertalite was varied by 0%, 5%, 10%, 15%, 20%, and 25%.

Data analysis. The data obtained were analyzed descriptively by looking at trends or comparison charts using Microsoft Excel to determine the significance of the influence of the variations carried out in this study on the reduction of CO and CO_2 exhaust emissions and the efficiency of fuel consumption on the test engine.

Research framework. The research framework is the rationale and stages of research that are arranged systematically. The framework is embodied in the flow diagram of the research implementation framework, as shown in Figure 3.

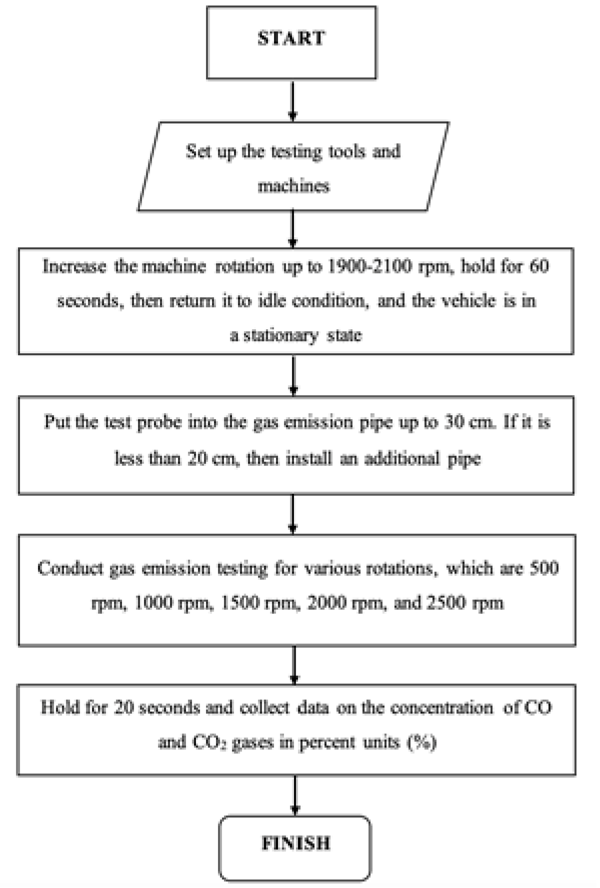

Figure 2. Gas Emission Testing Workflow

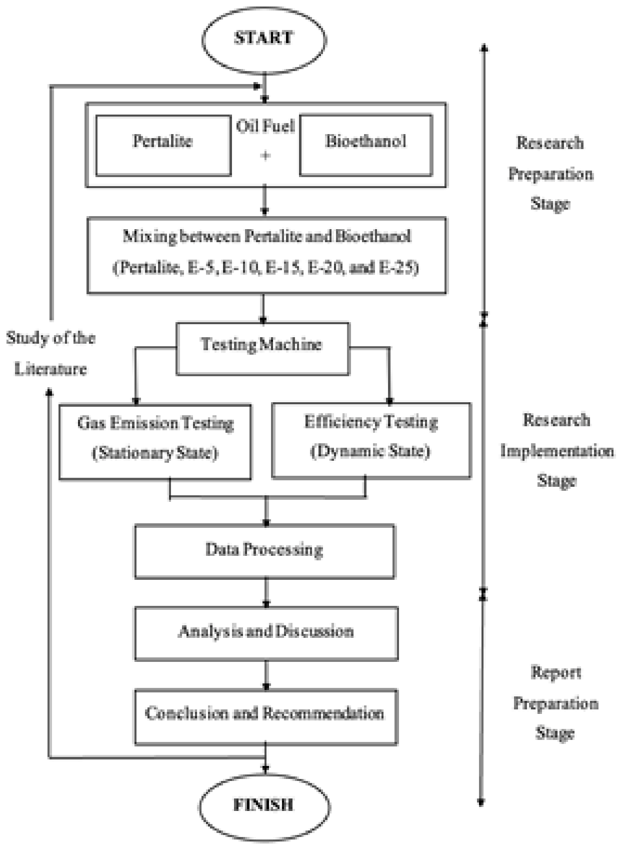

Figure 3. Research Framework

3. Results and Discussion

Exhaust emission test. The following are the results of the exhaust emission test.

Carbon monoxide gas emission levels. The test results of the measured CO levels from exhaust gas emissions in the Suzuki Carry ST100 minibus due to Pertalite and Pertalite mixed bioethanol (E-0, E-5, E-10, E-15, E-20, and E-25) fuel combustions through readings on the automotive emissions from the QROTECH QRO-402 analyzer is presented in Figure 4.

As shown in **Error! Reference source not found.**, the highest CO emission value (3.67%) was obtained at 1500 rpm engine speed using the standard Pertalite fuel. As the percentage of the bioethanol increased in the Biopertalite, a decrease in CO emission levels was observed. Similar results are obtained in the research conducted by Sebayang *et al*. in 2020 which used Pertalite and bioethanol mixture with E-10, E-15, and E-20 composition to test the CO emission [4]. The research on engine performance was carried out on a Daihatsu gasoline engine, two cylinders with a volume of 550 cc, and four strokes [4]. The dynamometer is integrated with the engine system and control unit [4]. Exhaust emissions were analyzed using BOSCH BEA 35 [4]. The result shows the higher the mixture value of gasoline and bioethanol and rpm of the engine, the lower the volume fraction (%) of released CO [4]. Figure 4 shows that the lowest concentration of CO gas emissions (0.18%) was observed when the fuel composition has 20% bioethanol or E-25 at 2500 rpm engine speed.

Based on the results shown in Figure 4, the CO gas emissions for all mixtures does not exceed the threshold set by the Ministry of the Environment because it is still below the emission threshold. Based on the regulation of the Minister of the Environment No. 5 of 2006 concerning

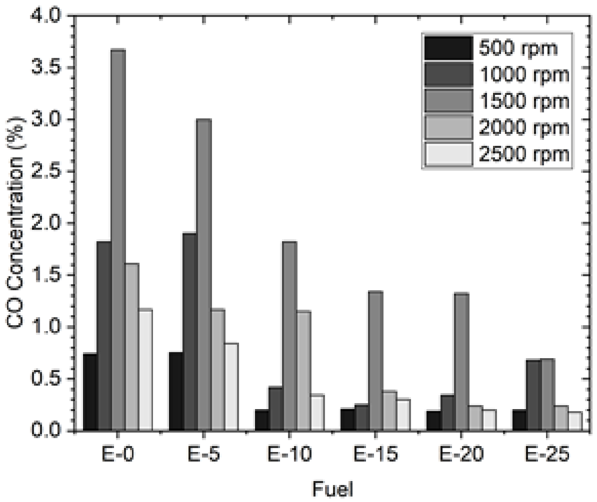

Figure 4. CO Concentration Levels at Different Fuel Compositions and Engine Speed

the exhaust emission threshold for old, motorized vehicles, the CO exhaust gas parameter for four-wheeled vehicles under 2007 is set at 4.5% [11]. Hence, the use of Pertalite alone is sufficient to meet these regulations. However, if you use a stricter threshold of 1.5% for vehicles over the year 2007, then the only fuel variations that can meet the criteria are E-15, E-20, and E-25 for all rpm variations. Thus, the use of bioethanol can reduce CO emissions by up to 86% on the E-15 type with 1000 rpm rotation.

The formation of CO emissions is due to the incomplete combustion process [12]. One of them is caused by a lack of oxygen in the carburetor so that many C atoms (carbon) do not get sufficient oxygen in the combustion chamber, leading to the formation of the CO, which is exhausted. The addition of biofuel in the form of bioethanol in Pertalite can reduce CO emissions. Bioethanol with the chemical formula C_2H_5OH, has one OH molecule, which helps improve the combustion between air and fuel mixtures in the carburetor [13].

Hydrocarbon (HC) gas emission levels. The test results of measuring HC levels from the exhaust gas emissions in the Suzuki Carry ST100 minibus due to the combustion of Pertalite and Biopertalite (E-0, E-5, E-10, E-15, E-20, and E-25) fuels through readings on the automotive emission from the QROTECH QRO-402 analyzer are presented in Figure 5.

As shown in **Error! Reference source not found.**, the concentration of HC emissions increased by 36% in the E-25 type at 500 rpm rotation. Concentration of the HC will be lower at a higher engine rpm. This result is similar to the result of previous research conducted by Octaviani, Irsyad, and Reksowardjojo in 2010 [14]. The increase in HC emissions indicates that the fuel is more volatile, thereby increasing the exhaust gas emission levels. This is caused

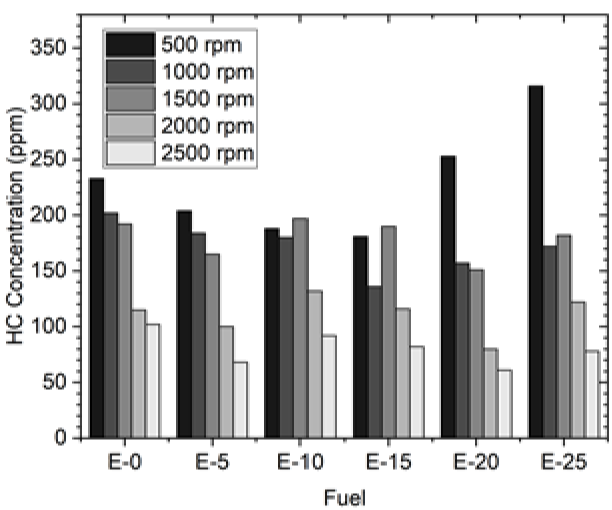

Figure 5. HC Concentration Levels at Different Fuel Compositions and Engine Speed

by an incomplete fuel combustion or a leak in the intake manifold. The high HC emissions are due to the fuel combustion failure. The high HC emisssions might be a result of difficulty in starting the engine, which causes the spraying speed to be low and makes the mixing of fuel with air relatively slow. This failed fuel is read as HC emissions on the auto emission analyzer [15]. HC emissions are also closely related to the oxygen content mixed in the fuel and depend on the air/fuel ratio to allow complete combustion to occur. Other causes that can cause increased HC emissions are damaged spark plugs or spark plug wires, too reversed ignition timing, and low engine compression [16].

CO_2 gas emission levels. The test results of measuring CO_2 levels from exhaust gas emissions from the combustion of the Suzuki Carry ST100 minibus using Pertalite fuel and variations in bioethanol mixing (E-0, E-5, E-10, E-15, E-20, and E-25) through readings on automotive emission from the QROTECH QRO-402 analyzer are presented in Figure 6.

CO_2 emissions produced by gasoline to be 2.33 kg/L [17]. Conversely, CO_2 emissions produced by bioethanol are 0.2 kg/L [18].

CO_2 emission mass calculations were performed for each type of bioethanol mixing variation data (E-0, E-5, E-10, E-15, E-20, and E-25) and engine speed variations (500, 1000, 1500, 2000, and 2500 rpm). The formulation used to calculate CO_2 emission mass is shown in Eq.(1) by assuming that CO_2 emissions produced by Pertalite are the same as gasoline emissions in general (2.33 kg/L).

$$CO_2\ emission\ mass\ (kg) = \frac{\%\ CO_2\ emission}{100} \times \left[\left(\%\ Pertalite \times 2{,}33\,\frac{kg}{L}\right) + \left(\%\ bioethanol \times 0{,}2\,\frac{kg}{L}\right)\right] \quad (1)$$

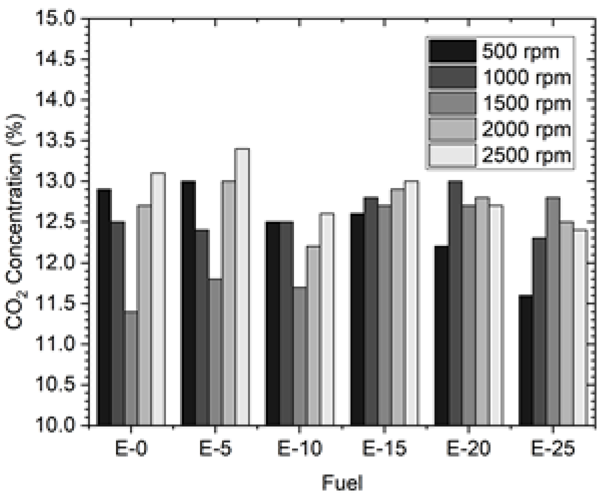

Figure 6. CO_2 Emission Mass at Different Fuel Compositions and Engine Speed

As shown in **Error! Reference source not found.**, the higher the addition of the bioethanol mixture to Pertalite fuel, the lower the mass of CO_2 emissions produced. This shows the same result as research conducted by Sari and Barlianti in 2009 [19]. The research conducted by Octaviani, Irsyad, and Reksowardjojo in 2010 also showed that CO_2 emission levels could be reduced by using a mixture of gasoline and bioethanol [14]. This finding proves that mixing bioethanol with Pertalite fuel can reduce the mass of CO_2 emissions in the environment [13]. The emissions produced by one unit of motorcycle and car with Pertalite fuel with 500 rpm engine speed are 0.415 and 0.105 tons/year, respectively. Meanwhile, the emissions produced for one unit of motorcycle and car with 25% Biopertalite fuel with 500 rpm engine speed are 0.313 and 0.073 tons/year, respectively. Thus, the use of 25% Biopertalite can reduce emissions by 30.6%.

Fuel efficiency test. The following are the results of the fuel efficiency test.

Fuel efficiency versus distance. Based on tests on car performance on public highways in the Tembalang area and its surroundings with a control variable in the form of 1 L of fuel and a speed varying according to the conditions of the busy highway, the car runs smoothly with speeds between 0–40 km/h using Biopertalite fuels, E-0, E-5, E-10, E-15, E-20, and E-25. This efficiency test was performed thrice so that the average distance measurement was obtained. The test results of the fuel efficiency on the mileage with a speed between 0–40 km/h are presented in Figure 7.

Error! Reference source not found. shows that the concentration of bioethanol in the Pertalite fuel mixture is directly proportional to the distance traveled, i.e., as the bioethanol percentage increases, the distance traveled by the vehicle also increases. It is the same as the result of the previous research conducted by Ubaidillah, Priangkoso, and Darmanto in 2021 [20].

Cost efficiency versus distance. The cost of fuel is currently a sensitive issue, with oil prices rising sharply. Energy prices are expected to rise by 50% in 2022, reflecting an increase of 81% in coal prices, 74% in natural gas prices (average of the European, Japan, and US benchmarks), and a 42% in oil prices [21]. Additionally, the price of energy commodities is expected to be 46% higher on an average in 2023 [21]. This price volatility is driven by a strong demand is due to a recovery from the pandemic, numerous pandemic-related supply constraints, and Russia’s invasion of Ukraine.

The fuel cost analysis was conducted with the condition that the initial price of Pertalite is USD 0.49, the latest price for Pertalite is USD 0.64, and the economic price for Pertalite is USD 0.92 [22–23]. The fuel cost efficiency is shown in Figure 8.

From these data, it can be concluded that mixing various bioethanol can significantly improve the cost efficiency. This increase in cost efficiency is correlated to the increased fuel efficiency of the Biopertalite products, where a higher mileage that can be achieved with 1 L of fuel lowers the fuel price per kilometer, increasing the cost efficiency.

Error! Reference source not found. shows that the highest fuel efficiency value is obtained with the E-10 fuel variation for Pertalite initial price, which is 0.8%. Pertalite initial price is subsidized by the government and its fuel cost efficiency is 47.1% for the distance traveled. Figure 8 shows that USD 0.59 can cover 10.4 km, which is better when compared to that using Pertalite, where USD 0.49 covers 8.5 km.

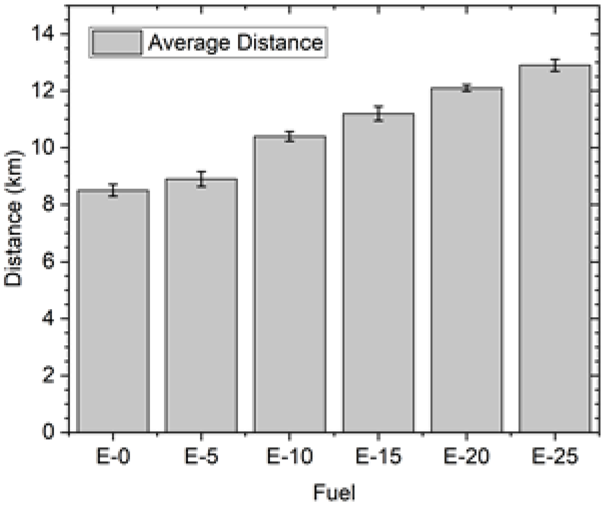

Figure 7. Fuel Efficiency Test Results

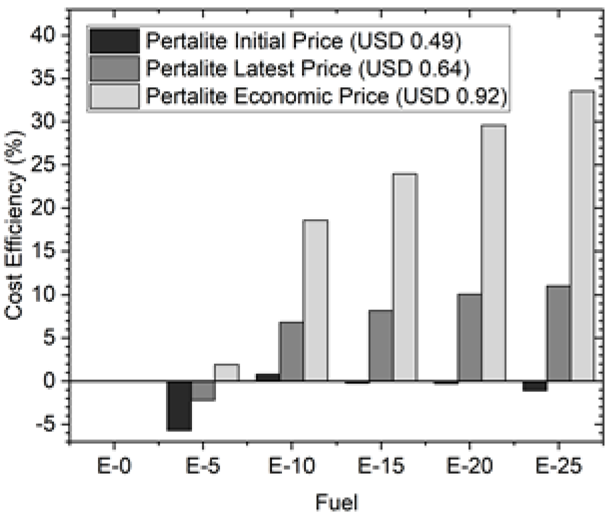

Figure 8. Cost Efficiency Test Results

In addition, the fuel cost efficiency with a Pertalite subsidy of 30.8% of the mileage (E-25) provided the highest fuel efficiency value of 11%. Moreover, a cost of USD 0.86 can cover 12.9 km, which is significantly better than that using Pertalite, which costs USD 0.64 to cover 8.5 km.

Furthermore, when using fuel data, the economic value of Pertalite is USD 0.92. Hence, the government plans to increase the price of fuel to reach its economic value in 2022. Figure 8 shows that the highest cost efficiency is 33.6% for the E-25 fuel variation.

Therefore, the results show that mixing bioethanol to Pertalite can increase the cost efficiency. This increase in cost efficiency is related to the increase in the fuel efficiency of the Biopertalite product, which is described in previous explanation. The higher the mileage that can be achieved with 1 L of fuel, the lower the price of fuel per kilometer, hence the cost efficiency increases.

4. Conclusions

The concentration of CO gas and mass CO_2 emissions decrease with the increase in the bioethanol mixture percentage in the fuel. The use of Biopertalite can reduce the concentration of CO gas emissions by up to 86% using the E-15 with a rotation of 1000 rpm. The use of Biopertalite can reduce mass CO_2 emissions by up to 30.6% using the E-25 type with 500 rpm rotation.

The average mileage of the test engine using Pertalite fuel (E-0) is 8.5 km, and it increases after mixing bioethanol (the average mileages of E-5, E-10, E-15, E-20, and E-25 are 8.9, 10.4, 11.2, 12.1, and 12.9 km, respectively). Furthermore, the average mileage of the test engine increased to 51.76% as the percentage of the bioethanol mixture in the fuel increased. Mixing bioethanol can also increase the cost efficiency up to 33.6% using the E-25 type with the reference price (i.e., Pertalite economic value) of USD 0.92.

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