Effects of Bioadditives and Commercial Additive on the Performance and Exhaust Emissions of a Gasoline Engine

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Abstract. One of our era’s greatest scourges is air pollution, on account not only of its impact on climate change but also its impact on public and individual health due to increasing morbidity and mortality. However, future climate change may exacerbate such human health impacts by increasing the frequency and duration of weather conditions that enhance the exposure to air pollution. Jakarta’s expanding fleet of motor vehicles is a key target of urgently needed actions to curb the hazardous air pollution in the city. This paper highlights the technologies and policies to reduce direct emissions from new and in-use cars, trucks, and buses in the city. Such policies, coupled with the promotion of mass transit, non-motorized transport, and other smart growth measures aimed at reducing transport demand, can significantly diminish the adverse effects of transportation on local air quality and public health in Jakarta, and spur similar actions across Indonesia. One of them is the addition of bioadditives (essential oils) and commercial additives that are widely sold in the market. In this study, the effects of essential oils (citronella oil and clove oil) as bioadditives and commercial additive on the performance and exhaust emissions of a single-cylinder, four-stroke gasoline engine was investigated, where both oils were blended with gasoline with a research octane number of 88. Based on the results, the maximum reduction in fuel consumption (33.33%) was obtained at an engine load of 43% when pure gasoline (G88) was blended with 0.1% of citronella oil and 0.1% of clove oil. This test fuel was labelled as BA2. The average reduction in fuel consumption was 18.54% for this test fuel. The thermal efficiency of the BA2 blend was higher even though it had the lowest volumetric efficiency compared with other blends. The unburned hydrocarbon (HC) and carbon monoxide emissions for the G88 fuel were 7 ppm and 0.202%, respectively, whereas the values were 20 ppm and 0.289%, respectively for the G88 fuel blended with Cleanozi commercial additive (CA1 blend). The HC and CO emissions were 11 ppm and 0.386%, respectively, for the G88 fuel blended with 0.1% of patchouli oil and 0.1% of clove oil (BA1 blend) whereas the values were 26 ppm and 0.631%, respectively, for the BA2 blend. Even though the BA2 blend had the highest HC and CO emissions, the values were still below the permissible limits for automotive vehicles in Indonesia.

Keywords: Bioadditive, Citronella oil, Clove oil, Patchouli oil, Exhaust emissions, Gasoline engine.

1. Introduction
In the last century, the use of cars as a means of transport has spread all over the entire globe. As with any other products, cars have shaped not only the global economy but how billions of people live. This can be seen from the data released by the Central Bureau on Statistics (BPS), where the number of vehicles in 2018 was 146,858,759 units, which was higher than that in 2017 (137,211,818 units). Most of the vehicles were motorbikes, followed by passenger vehicles [1]. This increases the amount of exhaust emissions produced by automotive vehicles, resulting in air pollution. The reduced production of fossil energy coupled with Indonesia’s increasing dependence on fossil fuels (especially petroleum), as well as efforts to reduce greenhouse gas emissions, has forced the Government of Indonesia to promote the use of renewable energy. In accordance with the government policy (PP), 79 out of 2014 concerning the National Energy Policy, the target of renewable energy is at least 23% in 2025 and 31% in 2050 [2]. Therefore, in recent years, many researchers have focused on energy conservation and therefore, their research is centered on exploring renewable fuels and fuel efficiency in order to reduce the need for fossil fuels. One of the solutions is to use additives, with the aim to improve combustion performance, and reduce exhaust emissions and fuel consumption.

There are two types of fuel additives, namely: (1) synthetic additives and (2) bioadditives (additives derived from plants). Ma’mun et al. [3] classified the additives into two types, namely, (1) metal organic compounds (metallic compounds) and organic non-metals (nonmetallic compounds). Lead (Pb) metal organic compounds produce toxic exhaust gases, where ~95% of of this heavy metal will be released into the air during combustion, which is a potential health hazard in the long term [3]. Indonesia is a country that produces essential oils, and these oils are easily obtainable. The use of essential oils as additives has been studied by many researchers. The addition of clove and citronella oil into biodiesel changes the heating value, viscosity, and density of the biodiesel. The aromatic compounds in essential oils can move the active building blocks of petroleum and reduce fuel consumption. This movement causes the bonds between the molecules to become weak and flammable. In addition, the presence of branched hydrocarbon bonds in essential oils can improve the fuel quality. Owing to the chemical structure of bioadditives, the specific fuel consumption of the fuel can be reduced because essential oils consist of two oxygen atoms, which can provide oxygen to ensure a more complete combustion [4].

The commonly used bioadditives are essential oils that have characteristics similar to fossil fuels in terms of the specific gravity, boiling point, and volatility. Patchouli oil, citronella oil, and clove oil are potential essential oils that can be used as additives for diesel and gasoline because based on their constituent compounds, these materials have a cyclic chain and sufficient oxygen availability. One of the essential oils that can be used as additives is clove oil. Clove oil contains plenty of eugenol, which is composed of several atoms including oxygen atoms. Owing to the presence of oxygen atoms in the chemical structure of eugenol, it is believed that the combustion process will be more optimal. However, the presence of these oxygen atoms can cause corrosion, which can lead to engine breakdowns. To overcome this problem, a corrosion inhibitor is used, namely, citronella oil. Citronella oil can reduce corrosion because this oil contains carboxylate compounds (–COOH). Essential oils are organic materials with great potential to be used as fuel bioadditives because they are volatile, and they have low specific gravity and viscosity. In addition, essential oils are composed of oxygenated hydrocarbon compounds and they can be completely dissolved in fuel for certain types of volatiles [5–15].

The objective of this study was to investigate the effects of bioadditives (citronella oil, clove oil, and patchouli oil) and commercial additive (Cleanoz) on the performance, exhaust emissions, and fuel consumption of a single-cylinder, four-stroke, gasoline engine, where the additives were blended with gasoline with a research octane number (RON) of 88.
2. Experimental Description

2.1 Test Fuels
The fuel used in this study is gasoline (RON 88), where the fuel was mixed with citronella, clove and patchouli oils with different compositions. A commercial additive, Cleanoz, was also used for comparison. The test fuels are presented in Table 1.

| Formulation | Label  |
|-------------|--------|
| Gasoline RON 88 | G88    |
| G88 + Patchouli oil (0.1%) + Clove oil (0.1%) | BA1    |
| G88 + Citronella oil (0.1%) + Clove oil (0.1%) | BA2    |
| G88 + Commercial additive (Cleanoz) | CA1    |

2.2 Experimental Setup and Test Conditions
Engine tests were performed using TQ engine test apparatus (TD 200), which consists of a single-cylinder, four-stroke, air-cooled gasoline engine. The test data were recorded using a data acquisition unit (VDAS). The test engine was set to run at a constant speed of 2000 rpm. The specifications of the test engine are tabulated in Table 2. The test engine was connected to a hydraulic dynamometer. The schematic and photograph of the test engine are shown in Figure 1 and Figure 2, respectively.

| Specification        | TQ TD200   |
|----------------------|------------|
| Type                 | Kohler     |
| Rated power          | 2200 W     |
| Number of cylinders  | 1          |
| Compression ratio    | 8.5 : 1    |
| Bore × Stroke        | 70 mm × 54 mm |
| Cylinder volume      | 0.208 L    |
3. Results and discussion

This results obtained from the engine tests are presented and discussed in this section.

3.1 Effects of Bioadditives and Commercial Additive on the Performance of the Test Engine

Figure 3 shows the effect of bioadditives and commercial additive on the brake specific fuel consumption (BSFC) of the test engine. In general, the BSFC of the test engine decreases as the engine load increases (i.e. the amount of fuel that enters the combustion chamber increases). The BSFC is highest when the engine load is lowest and continues to decrease as the engine load increases, and the BSFC eventually stabilizes.
Figure 3. Variation of the BSFC with respect to the engine load for all test fuels.

Figure 4 shows the effect of the bioadditives and commercial additive on the thermal efficiency of the test engine. It can be seen that the BA2 blend gives the highest thermal efficiency. It can be also seen that there is a relationship between the BSFC and thermal efficiency. When the BSFC is lowest, the thermal efficiency is highest. This indicates that as the thermal efficiency increases, more fuel can be burned to produce more power, which is then released through the engine crankshaft [16]. Thus, if the BSFC increases, the thermal efficiency decreases, which indicates that more fuel is wasted along with the remaining combustion gases, because the fuel is not burned completely to produce more power. The thermal efficiency indicates how much energy from the fuel is converted into power. Although the amount of air-fuel mixture that enters the cylinder is greater (which means that the fuel energy is greater), not all of this energy is converted into mechanical energy. In general, the rule of thumb for good combustion is that one-third of the chemical energy in the fuel is converted into mechanical energy.

Figure 4. Variation of the thermal efficiency with respect to the engine load for all test fuels.
Figure 5 shows the effect of the bioadditives and commercial additive on the fuel consumption of the test engine. It can be observed that the highest fuel consumption reduction is achieved for the BA2 blend (up to 33.33%) relative to that for pure gasoline.

Figure 6 shows the effect of the bioadditives and commercial additive on the volumetric efficiency of the test engine. In general, the highest volumetric efficiency is achieved for the BA1 blend. The volumetric efficiency is one of the vital performance parameters of an internal combustion engine. The volumetric efficiency is defined as the ratio of the volume of air or charge drawn into the cylinder to the total displacement of all cylinders. The volumetric efficiency is also defined as the ratio of time (in seconds) during the intake to the time (in seconds) at atmospheric pressure. In other words, the volumetric efficiency indicate the engine’s capacity to do work efficiently.

The volumetric efficiency reveals where the air-fuel mixture enters the cylinder. The air-fuel mixture that enters the cylinder during this step is what produces power. The power generated by the engine is directly proportional to the mass ratio of air-fuel mixture that enters the cylinder. The volumetric efficiency significantly affects the moment generated on the crankshaft, because the amount of fuel that can be absorbed into the cylinder will determine the heat generated as a result of fuel combustion. This in turn, will affect the final combustion pressure used to drive the piston, where the piston is directly related to the piston rod and the piston rod will push the crankshaft.
3.2 Exhaust Emissions

The exhaust gas emission data collection was carried out at an engine speed of 2000 rpm, and the results are presented and discussed in this section.

3.2.1 Carbon Monoxide (CO) and Carbon Dioxide (CO\(_2\)) emissions. Figure 7 shows the effect of the bioadditives and commercial additive on the CO and CO\(_2\) emissions of the test engine at 2000 rpm. In general, the addition of additives reduces the CO levels and increases the CO\(_2\) levels, except for the BA2 blend, where the CO level is higher than the CO\(_2\) level. CO results from incomplete combustion of carbon compounds, which often occurs in internal combustion engines. CO is formed when there is a lack of oxygen during the combustion process. CO produces a blue flame and it is flammable. CO can produce CO\(_2\). CO is a combination of carbon and oxygen, which is formed as a result of incomplete combustion whereas CO\(_2\) is produced as a result of complete combustion. CO gas is unstable and tends to react with other elements. CO can be easily converted into CO\(_2\) with some oxygen and heat. Hence, the CO\(_2\) concentration indicates the status of the combustion process in the combustion chamber. The higher the CO\(_2\) concentration, the better the combustion process. The CO concentration is also indicative of the combustion efficiency in the combustion chamber. A higher CO concentration indicates that there is lack of oxygen for complete combustion.

3.2.2 Hydrocarbon (HC) and oxygen (O\(_2\)) emissions. Figure 8 shows the HC and O\(_2\) emissions of the test engine at 2000 rpm for all test fuels. HC emissions are essentially fuels that do not burn in the combustion chamber. It can be observed that the BA2 blend produces the highest HC emissions, indicating that the combustion is incomplete in the combustion chamber. HC is a compound consisting of the element carbon atom (C) and hydrogen atom (H). All HCs have carbon chains and the hydrogen atoms are attached to these chains. The emissions for gasoline engines are HC compounds, where the HCs present in the vehicle exhaust gas indicate the presence of unburned fuel and are wasted as combustion residue. HCs can burn completely by reacting with O\(_2\), producing CO\(_2\) and water (H\(_2\)O). In general, higher HC emissions are undesirable because this indicate that there is excess of unburned

![Diagram](image-url)

**Figure 6.** Variation of the volumetric efficiency with respect to the engine load for all test fuels.
gasoline, which may be caused by failure of the ignition system or incomplete combustion. The HC concentration is measured in parts per million (ppm). The O$_2$ concentration in the vehicle exhaust emissions indicates the amount of air entering the combustion chamber in proportion to the amount of gasoline. The ideal figure for O$_2$ in exhaust emissions is within a range of 1–2%. A high O$_2$ concentration indicates that the air-fuel ratio is lean.

**Figure 7.** CO and CO$_2$ emissions of the test engine at 2000 rpm for all test fuels.

**Figure 8.** HC and O$_2$ emissions of the test engine at 2000 rpm for all test fuels.

4. Conclusion

The effects of bioadditives and commercial additive on the performance and exhaust emissions of a single-cylinder, four-stroke, gasoline engine have been investigated in this study in order to improve the current understanding on the effects of these additives on the combustion process. The highest reduction in fuel consumption is achieved for the BA2 blend (33.33%) at an engine load of 43% relative to that for pure gasoline (G88). The average reduction in fuel consumption was 18.54% for this fuel blend. The BA2 blend resulted in higher thermal efficiency even though it had the lowest volumetric efficiency.
compared with other blends. The following results were obtained for the exhaust gas emissions. The HC and CO emissions for the G88 fuel were 7 ppm and 0.202%, respectively, whereas the values were 20 ppm and 0.289%, respectively, for the CA1 blend. The HC and CO emissions were 11 ppm and 0.386%, respectively, for the BA1 blend whereas the values were 26 ppm and 0.631%, respectively, for the BA2 blend. Even though the BA2 blend had the highest HC and CO emissions, the values were still below the permissible limits for automotive vehicles in Indonesia.

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