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Analysis of emission gas and fuel consumption on SI engine fueled with low-grade bioethanol and oxygenated cycloheptanol additive

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Abstract. The use of alternative energy source is expected to reduce fossil energy consumption and exhaust emissions. One of the non-fossil energy alternatives introduced for vehicles is bioethanol, it can produce in a simple way and cheap. Low-grade bioethanol has characteristics that depend on exhaust emissions generated. Low-grade bioethanol can be used as a substitute or mixture of fuel. The mixture of bioethanol and gasoline gives an effect to the increase of octane number and reduces the emission of CO2 produces. To get a more optimum effect on fuel consumption and emission, the oxygenated additive can be added to the fuel mixture. In this study, the effect of fuel consumption and emission was carried out by comparison of E5, E10, E15 without additive and with additive oxygenated cycloheptanol. The test will be performed by the method of calculating the amount of fuel consumption against the time to get specific fuel consumption. Emission test will be performed in single cylinder spark-ignition (SI) engine 150cc premix fuel with 100% opening throttle position connected to the gas analyzer in variation speed engine to see the emission gas. This study aims to obtain reduce the emission gas (CO2 and CO) and fuel consumption with the addition of the oxygenated additive.

1. Introduction

The limited resources of fossil energy and the increasing need for fuel causes the necessity to finding another renewable energy source [1]. In addition, the increased fuel consumption that occurs today will cause the amount of exhaust emission generated increased and this will have an adverse impact on the environmental. Because of that problem, the use of regenerative fuels has been developed lately [2, 3]. By utilizing alternative energy that is environmentally friendly and widely available in nature is expected to be a solution that addresses current problems. One of the alternative energy developed today is biofuel. Biofuel can be used as a substitute for fuel or mixture on fuel [4]. Biofuel consists of several types including bioethanol, biodiesel, biobutanol, bio-methanol, biogas, biohydrogen, and vegetable oil. Currently, bioethanol and biodiesel are being developed to be used as fuel for the future.

Bioethanol is one of the renewable fuel sources derived from biomass product. Bioethanol is widely produced from agricultural residue (such as bagasse, rice straw, corn straw, and wheat straw), industrial waste starch processing and lignocellulosic biomass (such as agricultural residues, woody biomass, algae, and industrial solid waste). Indonesia is a country that has abundant raw materials in the manufacture of bioethanol. Looking for the raw material is widely available, bioethanol can be produced on a large scale [5, 6].

Bioethanol is claimed as an environmentally friendly alternative fuel because the emissions produced are clean from the pollutants. Bioethanol/ethanol has the potential to substitute gasoline as the main fuel in the internal combustion engine. The Environmental Protection Agency (EPA) explains that NOx is one of the most harmful pollutants in the respiratory system. The use of ethanol as a fuel can reduce emission from NOx [6]. Ethanol (C2H5OH) is colourless, transparent, neutral, volatile, flammable, oxygenated liquid hydrocarbon, and has a sharp odor [7]. Ethanol is generally more reactive than hydrocarbon fuel. This is because of the content of hydroxyl radical as a polar fraction and carbon chain as a nonpolar fraction, so easily dissolved on nonpolar substances such as gasoline and also on polar substances like water [8].

The use of high-grade ethanol as fuel needs to be modified on an SI machine, whereas low-grade ethanol can be directly used without modifying the machine [9]. The advantages of ethanol compared to gasoline is high octane number, higher latent heat of ethanol that increases volumetric efficiency, contain more oxygen in the combustion process, lower vapor pressure can reduce the evaporative emission, high laminar flame propagation speed which makes combustion process to be finished earlier, ethanol increase thermal efficiency, allows use of high compression ratio without knocking and produce clear emission [10].

The efforts to reduce exhaust emission continue to be developed, one of the efforts is engineered fuel by adding additives to a mixture of the fuel. Methyl tert butyl ether (MTBF) is one of the most popular additives used as a mixture of fuel to increase octane number and reduce carbon monoxide and ozone [11]. However, MTBF has an adverse impact on the environment, there are several complaints related to the impact of MTBF use, including irritation of the eyes and lungs [12].

C. Ananda Srinivasan [13] studied the effect of a mixture of fuel gasoline-ethanol mixed with an oxygenated additive on a spark ignition machine. The experimental results prove that CO2, CO, and NOx emission decrease, while HC and O2 increase.

This study was conducted on SI machine by using another alternative in the form of oxygenated cycloheptanol as an additive used in the gasoline bioethanol fuel mixture. Comparison results emission gas and fuel consumption between additive fuel and without additive fuel can be seen in this paper. Cycloheptanol properties can be found in table 1.

2. Research Methodology

The test was performed on an SI engine 150 cc single cylinder with a fuel injection system using the injector. There are 7 fuel variables with the ratio of gasoline and bioethanol E0, E5, E10, E15 without additive and E5, E10, E15 with add 0.5 ml oxygenated cycloheptanol in every mixture.

2.1. Valve Opening Control

Gasoline engine with fuel injection generates the air-fuel mixture directly in the combustion chamber. Air flow through the intake valve in the open position and the fuel is injected directly into the combustion chamber using high-pressure injector controlled by ECU. Engine achieve the best performance with the right air-fuel ratio. Gasoline has AFR 14.7:1, the leaner mixture tends to degrade performance, while richer the fuel is waste and emission will be increased without substantially increasing performance. The lean setting in carburettors create some problems, the engine in the pre-emission law days was normally set up on the rich side. This made engine quick warm up, easy to start and provided good performance.

Electronic fuel injection systems consist of various sensors to know the exact engine condition. Sensors give an information about engine condition to the computer. After comparing that information to set of known parameters, the computer determines exactly the amount of fuel is required to maximize power while creating the lowest emission, then adjust air-fuel ratio for the combustion process. Electronic fuel injection allows the engine to receive the ideal mixture, neither so lean that is creating problem nor so rich that it exceeds emission standards.

Table 1. Properties of Cycloheptanol

Chemical Name	Cycloheptanol; 502-41-0; Suberol
Molecular Formula	C7H14O
Molecular Weight	114.118 g/mol
Appearance	Clear; colorless liquid
Melting Point	2ºC
Boiling Point	185ºC
Flash Point	60ºC
Density	0.9554 g/cm^3 (20ºC)
Heat of Vaporization	48.7 kJ/mol
Heat of Combustion	-4441 kJ/mol
Vapor Pressure	0.24 (25ºC)

2.2. Experimental Set Up

Figure 1 is set-up experimental in 150 cc SI engine that was supported to other components. Testing was done on the SI engine single cylinder that was mounted on a dynamometer chassis type MCD400L series by mainline dyno log and connected techno motor gas analyser to exhaust manifold. Dynamometer Calibration process was done by adjusting the rotation of the wheels of the vehicle with the round roller drum to obtain corresponding values between rpm engine and the results of the readings on a dynamometer. The test performs in the various rotation (4.000rpm, 6.000 rpm, and 8.000 rpm) for each variations fuel. The results of the emission gas were issued in the gas analyser monitor. The fuel consumption results issued in the graphics.

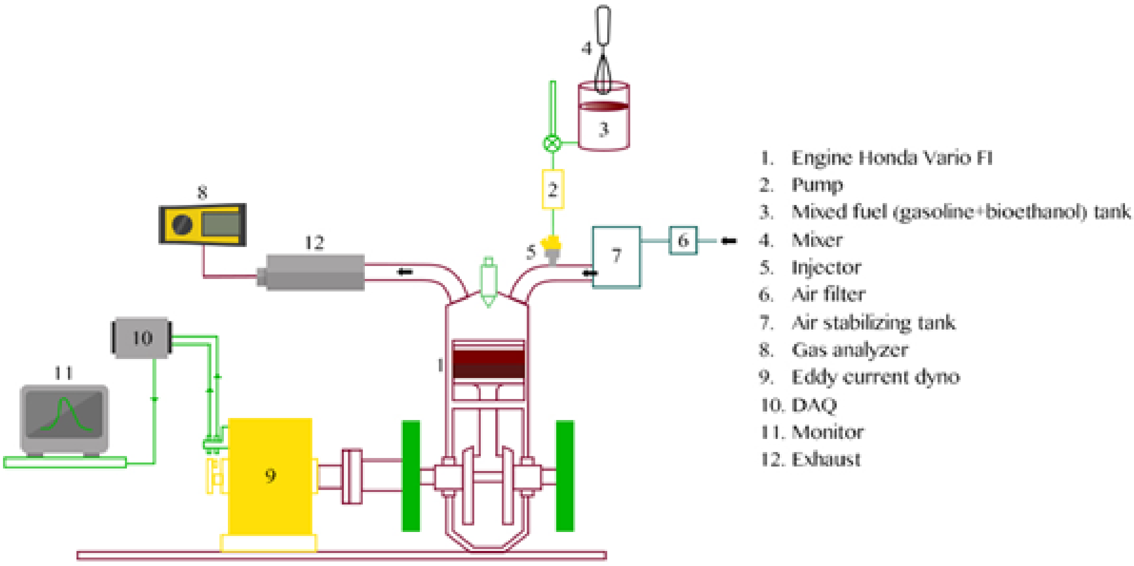

Figure 1. Experimental Set up Engine.

2.3. Exhaust Gas Emission

Techno gas analyser type Gas-810 was used in this study. The first test conducted in the collect exhaust emission data (CO, CO2, and O2). The test starts by connecting the hose from the gas analyser to exhaust manifold and were carried out from E0 to E15 +additives at each rotation of 4.000 rpm, 6.000 rpm, and 8.000 rpm. The results will be issued by the monitor in the gas analyser.

2.4. Fuel Consumption

The fuel consumption test performed by using the rate of fuel consumption unity of the time. Test conducted at 4.000 rpm, 6.000 rpm, and 8.000 rpm with 7 variations of fuel. Here is the procedure for this test:

1. Preparing each fuel variations. Put the fuel into the measuring tank that connected by hose into injectors.
2. Start the engine. Data retrieval starts at 4.000 rpm, the time was counting when the rotation hold in 4.000 rpm and 25ml of fuel used in constant rotation. The time is taken to consume 25ml of fuel will be calculated to get the specific fuel consumption.
3. The test performed on each variation of fuel at the variable rotation.

Specific fuel consumption is a parameter to determine the amount of fuel required to produce a certain amount of power in a certain time interval. The SFC is called the Brake Specific Fuel Consumption (BSFC) if it uses Power brake horse, and if using indicated Power then it is called Indicated Specific Fuel Consumption (ISFC).

3. Result and Discussion

The test was performed on variations of E0, E5, E15, and variations using oxygenated cycloheptanol additives. These tests include exhaust emissions in the form of CO, CO2, and O2. Here is the result of emission test results and fuel consumption of each fuel mixture variation.

3.1. The Result of Carbon Dioxide (CO_2)

The tests were performed at the variations engine rotate. (4.000 rpm, 6.000 rpm, and 8.000 rpm). Here is the graph of carbon dioxide gas emission test results.

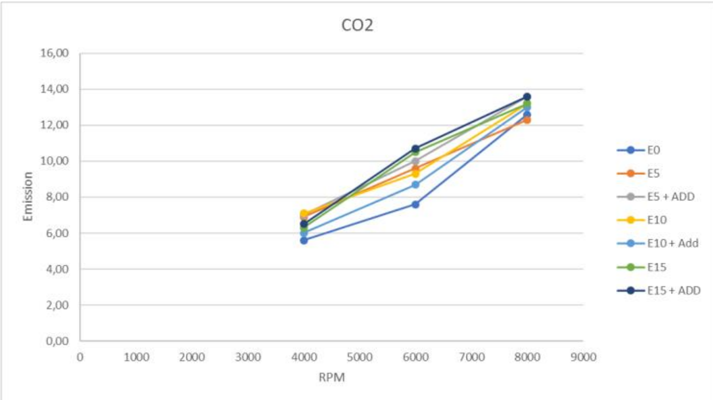

Figure 2. CO_2 vs Engine Speed.

As the engine rotation increases, the CO2 emission increase. This indicates that complete combustion in the combustion chamber. Based on the graph above shows that the addition of bioethanol can increase the CO2 level. In the variation of E5, E10, and E15 obtained the average of each rotation with a percentage respectively amounting to 9.6%, 9.87%, and 10%. For the percentage of gasoline (E0) at each rotation equal to 8.6%. An increase of 11.6% by E5, 14.7% by E10, and 16.2% by E15. As for the variations with additives yielded a percentage of CO2 with an average of 10.2% for E5 +additives, 9.23% for E10 +additives, and 10.27% for E15 +additives variations.

In general, the addition of oxygenated cycloheptanol to fuel variations result in the combustion cycle. The higher percentage of CO2 in combustion process indicates complete combustion in the combustion chamber. This happens because the oxygen molecules (-OH) in bioethanol and the additive reacts with CO and produce more CO2.

3.2. The Result of Carbon Monoxide (CO)

The results of the CO exhaust test in each fuel are averaged to represent the percentage of emissions in each rotation. From the test results, see that mixing of bioethanol and additives in the fuel results lower CO gas emission than E0. In E0 variation obtains the average percentage of each engine speed of 0.74%, it is higher than the average percentage obtained from the variation of E5 – E15 fuel mixture without additive and with an additive. Bioethanol can reduce CO emissions by up to 24%, while with the addition of CO additive has been reduced to 63% on E15 +additives of the CO produced by E0.

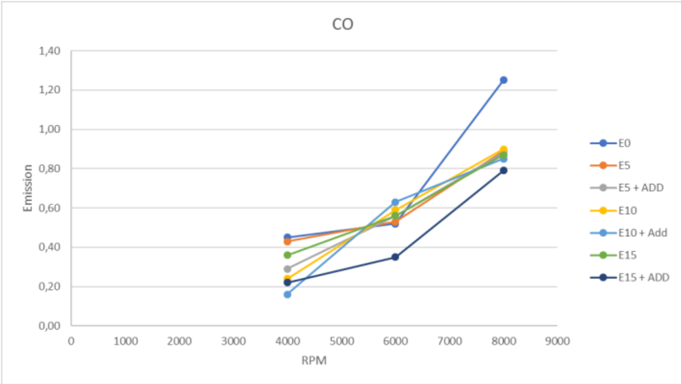

Figure 3. CO vs Engine Speed.

Figure 3 shows the effect of CO on fuel variations without additives and with additives. The addition of the oxygenated cycloheptanol additive to the fuel variations can reduce CO emissions by 0.14% in E15. CO comes from incomplete combustion products because of insufficient oxygen in the air-fuel mixture in the combustion cycle. The air-fuel ratio for ethanol is lower, in the stoichiometric conditions about 8.95:1, while for gasoline is 14.7:1. Therefore, the addition of ethanol and oxygenates into gasoline leads effective leaning on the mixture. The higher bioethanol mixture on the fuel can reduce CO, and by adding the oxygenated cycloheptanol it produced lower CO. This because of the -OH molecules are in bioethanol and additives produces complete combustion. Mixed fuels that contain lots of oxygen will help the process oxidation of CO to CO2. The percentage of CO emissions also depends on the operating conditions of the engine.

3.3. The Result of Oxygen (O_2)

Based on Figure 5, the percentage of oxygen generated from the mixed variation from E0 to E15 +additive while the O2 produced decreased by engine speed. In each engine speed obtained an average percentage of 0.18% for E0, 6.5% for E5, 6.13% for E10, and 6.02% for E15. On a variation fuel with additives yield a percentage of 7.67% for E5 + additives, 7.02% for E10 +additives, and 8.65% for E15 +additives.

The use of fuel variations results is higher O2 although is not too significant. The percentage of oxygen in the emission gas is inversely proportional to the CO2 concentration. Figure 4 can be seen the higher engine speed will reduce the O2 contain in emission gas. At the same time, the fuel variation with additives increases the O2 contain.

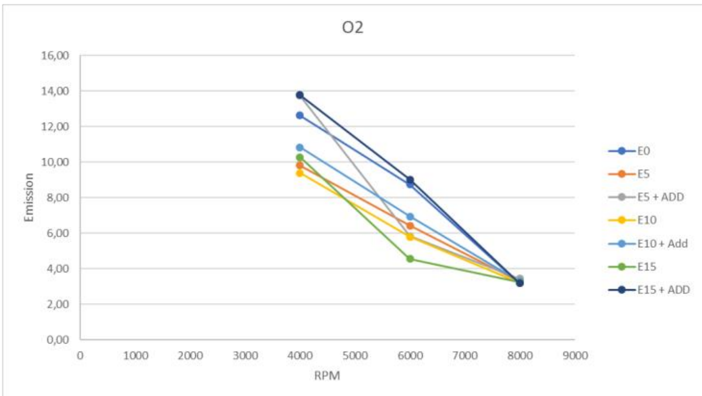

Figure 4. O2 vs Engine Speed.

3.4 The Result of Specific Fuel Consumption

Fuel consumption test was done by observing the amount of fuel consumption at a certain engine speed so that the data of fuel into combustion chamber per unit time was obtained. Figure 5 shows that fuels with bioethanol (E5, E10, E15) produce greater level consumption than gasoline (E0). This explains that the use of bioethanol in the fuel mixture impact on the fuel consumption. The large consumption fuel of bioethanol is due to the AFR stoichiometric of bioethanol is lower than pure gasoline with less air flow into the combustion chamber so that the mass of bioethanol fuel into the combustion chamber is more. Fuel mixture has a large flame speed that allows the fuel burning fast so that less burnt fuel burns and a complete combustion [14]. In the graph, can also be seen that the higher engine rotation the larger fuel consumption. This due to the shortening of combustion time resulting in higher engine rotation requiring greater fuel consumption.

Subsequent test results were carried out by adding an oxygenated cycloheptanol additive to the fuel variations E5, E10, and E15. The addition of additives results in lower fuel consumption, which means fuel consumption saving occurs in every variation of fuel mixed with additives. From the graph, can be seen the least fuel consumption occurs in the variation E5. At 4.000 rpm rotation fuel consumption produces 1L/H for E5, 0.9L/H for E5 +additives. While at 8000rpm rotation produces 2L/H for E5 and 1,3L/H for E5 additive.

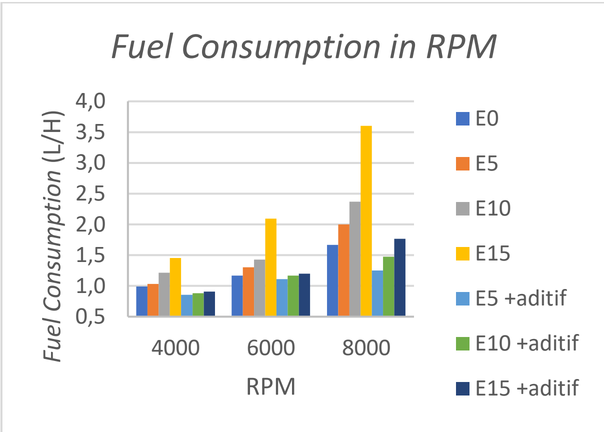

Figure 5. Fuel Consumption in RPM.

The specific fuel consumption (SFC) is defined as the ratio of the fuel mass flow rate to the generated power (output), SFC state how efficiently the fuel is supplied to the engine for output power. A low SFC value indicates an efficient fuel consumption, therefore a low SFC is desirable to achieve fuel efficiency.

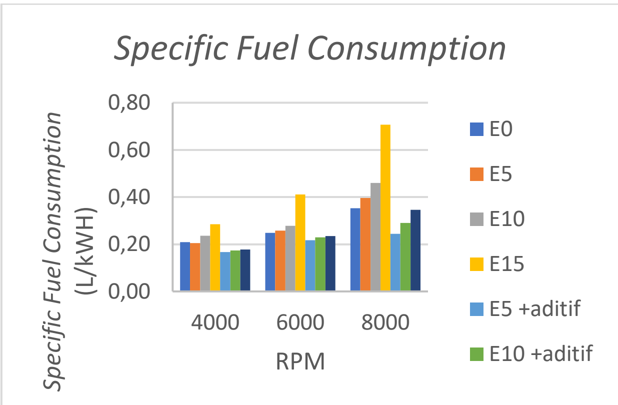

Figure 6. Specific Fuel Consumption.

Figure 6 shows that the smallest SFC is at the E0 variation on each engine speed. The gasoline bioethanol mixture yields a higher SFC value compared to E0. While for variations of fuel with additives produce smaller SFC values. The higher volume of ethanol causes the higher of fuel consumption. This is because the calorific value contained in ethanol (26,000 kJ/kg) is almost half times the gasoline (42,000 kJ/kg) contained because it requires more fuel to reach the equivalent amount of energy.

Fuel consumption is a representation of SFC, where at high engine speed the value of fuel consumption increases due to increased friction force. SFC is calculated by measuring fuel consumption. The addition of bioethanol and additives oxygenated cycloheptanol causes an increase in SFC. This influenced by heating value contained, the lower fuel energy content causing the increase of SFC even without any modification.

4. Conclusions

Based on the results of emission test and fuel consumption of bioethanol hydrate mixing with gasoline through fuel mixer mechanism, and the ratio of emission result and fuel consumption of bioethanol with gasoline, the following conclusions can be drawn as CO2 gas emissions are expected in the combustion cycle. The higher CO2 levels in combustion process indicate complete combustion in combustion chamber. This happens because the oxygen molecule (-OH) in the fuel reacts with CO and produce CO2. The mixture of gasoline and bioethanol can reduce CO emissions greater. The addition of the oxygenated cycloheptanol additive can reduce CO emission better. This occurs because of bioethanol and oxygenated cycloheptanol results in more effective combustion and greater oxygen content. The addition of additives in a fuel variations increase O2 contain in emission gas due to oxygen content in fuel increases. The addition of bioethanol and additives oxygenated cycloheptanol causes an increase in SFC at every engine speed compared to gasoline (E0).

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