Jurnal Presipitasi
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 20, No 3, 2023, 755-764
Article available at homepage presipitasi

Original Research Article

Analysis of Exhaust Gas Emission of Motor Vehicles with Variations of Fuel Types

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Abstract

The discrepancy between the use of vehicle fuel types and the vehicle's technical specifications is expected to affect exhaust emissions. This study aims to examine the effect of using four types of fuel with different octane number specifications on two four-wheeled motor vehicles with an EFI fuel delivery system on exhaust gas emission parameters of carbon monoxide (CO), hydrocarbon (HC), carbon dioxide (CO_2) and non-emitting gases Oxygen (O_2). With a quantitative experimental approach method using the Automotive Emission Analyzer and simple linear regression analysis, the results showed that the use of variations with octane numbers RON 98, RON 92, RON 90, and RON 88 fuels at the same time as variations in engine speed (1000 – 3000) RPM showed an effect on concentration. HC and CO emissions decreased with each increase in the octane number of fuel, RON 92 fuel with the lowest average CO / HC (0.0013% / 0.46 ppm) and RON 98 with the lowest average CO / HC (0.0026% / 0 ppm). The use of RON 92 fuel is more effective and inexpensive to apply to vehicles with an EFI fuel delivery system (with compression of 1:10/10.2) compared to RON 98 fuel which emits higher CO and HC emissions at low engine speed (1000 -1500) RPM.

Keywords: Carbon monoxide; EFI system; emission; fuel; hydrocarbon

1. Introduction

Land transportation, especially gasoline-fuelled vehicles, is a key factor in improving the economy of a region. The increasing activity of people who need land transportation is directly proportional to the need for this mode of transportation. Data from the Central Statistics Agency shows an increase in the number of motorized vehicles from a total of 126 million (2018) to 133 million units in 2019 with an annual growth of around 6.13% (BPS, 2019).

The increase in the number of vehicles resulted in a decrease in air quality. These air pollutant components may consist of carbon monoxide (CO), hydrocarbons (HC), carbon dioxide (CO_2), nitrogen oxides (NOx), and other particles of various sizes. According to research conducted by (Suryati et al., 2020) regarding the calculation of greenhouse gas emissions CO_2 equivalent to transportation in Medan City using the IPCC Tier 2 method (Suryati et al., 2020), it was concluded that CO_2 emissions are generated from the transportation sector per year as much as 4.29 million to 7 .01 million tons of CO_2 equivalent and will continue to increase if there is no mitigation.

Vehicle exhaust is the largest source of air pollution in the transportation sector. Factors that influence emissions include fuel type, vehicle type, and vehicle age. Different fuels and vehicle types affect fuel consumption. Fuel consumption is the most key factor in measuring emissions because it influences the amount of carbon emissions produced. Variations in vehicle age affect engine efficiency and combustion efficiency (Rusdiani & Ratna Rizky, 2018)

Due to the large levels of emissions produced by the transportation sector, various mitigations and solutions are needed to reduce the concentration of pollutant substances produced by burning fuel for motor vehicle energy. This solution can be in the form of using an EFI (Electronic Fuel Injection) fuel delivery system and using a standard type of fuel with a certain octane number according to the type of vehicle. The EFI system produces lower toxic exhaust emissions when compared to engines that use conventional systems, this is because the EFI system can measure fuel more accurately to each cylinder (Hillier V, 2012)

The type of fuel used as energy for motor vehicles is one of the important factors in controlling exhaust emissions in engines with EFI fuel delivery systems. Efforts to control the type of fuel can be made through standardization. Indonesia has started to apply the EURO 4 emission standard (Peraturan Menteri Lingkungan Hidup No. 20, 2017) with various considerations whereas previously Indonesia referred to the EURO 3 standard for most motorized vehicles today (Efendi et al., 2018). The EURO 4 standard for fuel is fuel with a minimum octane rating of 92 and is free of lead (Pb). The type of fuel that can meet the EURO 4 exhaust emission quality standards can be seen from the characteristics and octane number of the type of fuel.

According to research (Asropi Iskandar, 2019), there is an inconsistency with the implementation of the EURO 4 Emission Standard policy. This can be seen from non-compliance in purchasing EURO 4 standard fuel for customers who have EURO 4 standard vehicles that have EFI engine systems with high compression due to inadequate information. on customers. Percentage of sales of gasoline with an octane number of less than 92, namely Premium (RON 88) and Pertalite (RON 90) as much as 33.1% and 55% dominate sales in the community compared to gasoline with an octane number of 92 or more, Pertamax (RON 92) and Pertamax Turbo (RON 98) with 11.3% and 0.6% (Chaniago, D., 2020).

The update in this research is the use of research objects. The research object used here is a four-wheeled vehicle that has an EFI (Electronic Fuel Injection) fuel delivery system which is currently widely used by people in Indonesia. The results of this study are expected to provide information to the public about the selection of appropriate fuel vehicle specifications, especially those with EFI system engines, and support government programs in controlling mobile source air pollution, namely the implementation of Euro 4.

The use of electronic fuel injection technology (Electronic Fuel Injection (EFI) system) is an effort to improve the performance of petrol motorbike fuel systems and create low-emission vehicles. Electronic fuel injection systems are designed to improve the performance of petrol motorcycle fuel systems. The electronic fuel injection system is a set of tools to supply the fuel needed for combustion in a gasoline engine. This is a system that uses several sensors to detect the status of the engine and control unit (electronic circuit). Based on signals from existing sensors, the control unit regulates the amount of fuel injected into the combustion chamber and adjusts the air-fuel ratio to suit the engine operating conditions.

Electronic fuel injection systems have several advantages over carburetor fuel systems (Nugraha & Sriyanto, 2007): 1) Atomization as a function of engine operating conditions which are sensed by various sensors, increasing accuracy in regulating the amount of fuel released. As a result, the mixture composition is better adapted to the engine operating condition; 2) Fuel can be atomized directly into the inlet near the intake valve. This improves mixture homogeneity and improves fuel efficiency.

The purpose of this study was to analyze the effect of using different types of octane fuel on the exhaust emission characteristics of vehicle engines with EFI fuel delivery systems so that the conclusions from this study can be useful in providing information to the public and the government about the importance of selecting fuel. fuel and tighten regulations on the use of low-octane fuel to reduce exhaust emissions that are harmful to the environment.

2. Methodology

2.1. Research materials

The material used in this research is fuel distributed by state oil companies and widely used by the public. This fuel has an octane number of RON 98, RON 92, RON 90, and RON 88. The characteristics of the fuel content based on the Decree of the Director General of Oil and Gas can be seen in Table 1.

Table 1. Fuel content.

Composition in Gasoline	88	90	92	98
Pb	✓	-	-	-
oxygenate	✓	✓	✓	✓
aromatic	✓	✓	✓	✓
benzene	✓	✓	✓	✓
olefin	✓	✓	✓	✓
sulphur	✓	✓	✓	✓
Steam Pressure	max: 69 Kpa	max: 69 Kpa	max: 60 Kpa	max: 69 Kpa

Data collection was carried out with two vehicle objects with the same fuel delivery system but from different brands. The cylinder capacity is 1,198 cc and 1,373 cc with the manufacturer years 2015 and 2016, and the total engine mileage is 2239 km and 2439 km. Based on this data, it can be concluded that the condition of the vehicle is still very well maintained and it is rarely driven on the road. The data results may be different if a vehicle with a higher total distance traveled (>10,000 km) is used, but due to several research limitations, the vehicle objects that can be used are two units.

2.2. Measuring instruments and sampling procedures

The equipment used in collecting primary data on the concentration of exhaust emissions uses the Automotive Emission Analyzer *Heshbon* model HG-520, a thermometer to measure engine operating temperature. Equipment and measurement schemes can be seen in Figure 1.

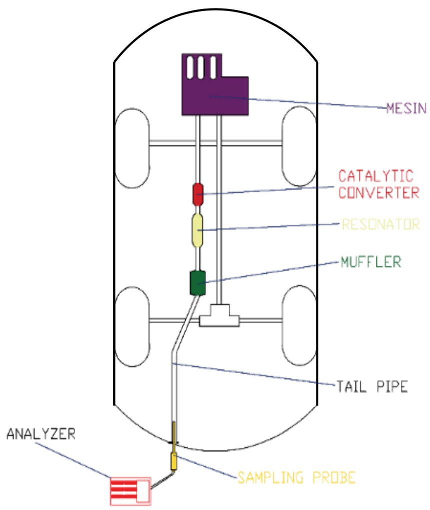

Figure 1. Equipment schematic.

The procedure for preparing the vehicle will apply references from the Indonesian National Standard (SNI) 09-7118.1-2005 concerning Methods for testing motorized vehicles of categories M, N, and O driven by spark ignition in idle conditions. The primary data collection procedure using the Automotive Emission Analyzer will apply references according to the manufacturer's recommendations for the Heshbon model HG-520 test equipment.

The measurement procedure for gasoline-powered vehicles was based on SNI 19-7118.1-2005 (BSN, 2005) which states the following regulations:

1). Preparations for vehicle testing shall be done as follows: (a) the vehicle that is about to be measured for emissions composition must be parked on an even surface. (b) the exhaust pipe is not leaking. (c) The engine must be at a normal operating temperature state between 60°C and 70°C or as recommended by the manufacturer. (d) The accessories system must be turned off. (e) The temperature at the workplace should be between 20°C and 35°C.

2). Equipment preparations for emission tests for gasoline-powered vehicles, and gas analyzers, must be done like the following: (a) Make sure all the tools are properly calibrated. (b) Turn them on according to the standard operating procedure.

3). Evaluation for CO, CO_2, and HC composition must be done by following these steps: (a) Prepare the vehicle that is about to be evaluated. (b) Prepare the testing equipment. (c) Raise the engine speed to 2.900 rpm until 3.100 rpm then hold steady for 60 seconds and then return it to its idle speed. (d) Then do an emission check in its idle state while running the engine at a speed of 600 rpm up to 1000 rpm or as recommended by the manufacturer. (e) At this point, do a probe test inside the exhaust pipe to a depth of 30 cm. If the depth of the exhaust pipe is less than 30 cm then an additional pipe may be attached. (f) Wait for 20 seconds and collect the data

The research was conducted with two factors: the first factor was the type of fuel with different octane values, and the second factor was engine speed (1000–3000 RPM). Each fuel is treated with variations in engine speed starting from 1,000 rpm to 3,000 rpm with 500 rpm intervals. Each type of fuel was repeated three times, so 300 (three hundred) data points were obtained from the total samples treated.

2.3. Method of Analysis Data

Data analysis in this research will explain the results of data analysis using the approach of inferential statistics to determine the hypothesis of differences between variables and determine trends relationship between the dependent variable and the independent variable. Analysis of the results of the data using the SPSS 18 application instrument.

The independent variables in this research are Pertamax Turbo fuel, Pertamax, Pertalite, and Premium, and variations in engine speed. Dependent variables in research are exhaust emissions of carbon monoxide (CO), hydrocarbons (HC), carbon dioxide (CO_2), and non-emission gas Oxygen (O_2). A summary of the data analysis methods used in this research can be seen in Table 2 below.

Table 2. Method of analysis data

Test Type	Output	Term of Conditions	Information
Residual Normality Test	One Sample Kolmogorov-Smirnov Test Table	Sign value/probability p > 0,05	residuals are normally distributed
Multicollinearity test	Multicollinearity Test Table	Tolerance > 0,1 and VIF < 10	do not experience symptoms of multicollinearity
Heteroscedastic test	Coefficients Table	Sign value/probability p > 0,05	The fuel type variable and the RPM variable do not have heteroscedastic symptoms

Test Type	Output	Term of Conditions	Information
linearity test	ANOVA Table	Sign value/probability p > 0,05	The RPM variable has a linear relationship with the emission gas concentration variable
Regression Analysis			
Test the suitability of the regression model	ANOVA Table	Sign value/probability p > 0,05	There is an RPM variable that has a statistically significant influence on the emission concentration variable
Significant test	Coefficients Table	Sign value/probability p > 0,05	RPM influences emission concentrations significantly

3. Result and Discussion

3.1. Comparison of CO and HC Concentrations

CO gas contains the element carbon (C) which is found in fuel components (approximately 85%of weight and the remainder of hydrogen) and burns incompletely due to a deficiency of oxygen. According to Kabib (2009), the highest CO levels occur in idling conditions and reach a minimum when the acceleration reaches a constant speed. CO levels too influenced by the fuel mixture, homogeneity, and air-fuel ratio. The good mixture quality and homogeneity will affect the oxygen reaction with carbon. The amount of oxygen in the air-fuel ratio is very determining The large amount of CO produced is due to the lack of oxygen in the mixture This will result in carbon reacting incompletely with oxygen.

Hydrocarbons are emissions that result from burning fuel that does not burn completely and come out with exhaust in the tailpipe, causing smog. The forming hydrocarbon compounds are produced by using exhaust gases to heat the incoming air, thereby increasing fuel evaporation. As the fuel evaporates, a certain amount of hydrocarbons is always present in the fuel tank, which is called blow-by gas, when gas leaks from the piston to the crankshaft through the gap between the cylinders (Ichsanudin G, 2023).

Based on the graph in Figure 2(a) regarding Type of Fuel vs. Average CO Concentration in vehicles with a cylinder capacity of 1,198 cc, the highest CO concentration is when using RON 88 fuel, with an average CO concentration of 0.0053%, and the lowest is when using RON 92 and RON 98 fuels, with an average CO concentration of 0.0013% and 0.0026%, respectively. The ranking based on the lowest to highest CO concentration is: 1) RON 92 (0.0013%); 2) RON 98 (0.0026%); 3) RON 90 (0.0033%); and 4) RON 88 (0.0053%).

Based on the graph in Figure 2(b) regarding the Type of Fuel vs. Average CO Concentration in vehicles with a cylinder capacity of 1,373 cc, the highest CO concentration is when using RON 98 fuel with an average CO concentration of 0.05%, and the lowest is when using RON 92 fuel with an average CO concentration of 0.014%. The ranking based on the lowest to highest CO concentration is: 1) RON 92 (0.014%); 2) RON 90 (0.026%); 3) RON 88 (0.033%); and 4) RON 98 (0.05%).

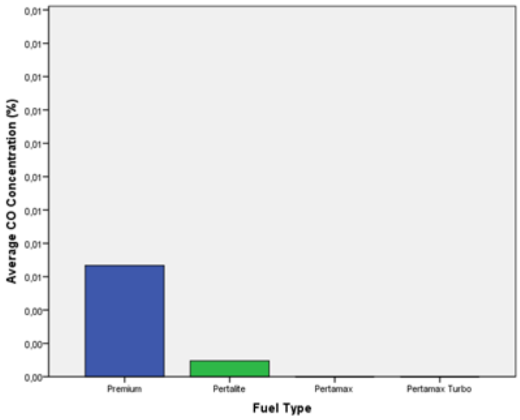

Figure 2(a). CO vs RON (1.198 cc)

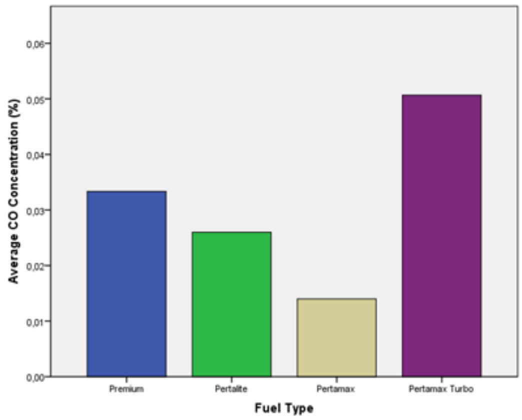

Figure 2(b). CO vs RON (1.373 cc)

Based on the graph in figure 3(a) regarding Fuel Type vs. Average HC Concentration in vehicles with a cylinder capacity of 1,198 cc, the highest HC concentration is when using RON 92 fuel with an average HC concentration of 0.46 ppm, and the lowest is when using RON 98 fuel with an average HC concentration of 0 ppm. The ranking based on the lowest to highest average concentration of HC is: 1) RON 98 (0 ppm); 2) RON 90 (0.13 ppm); 3) RON 88 (0.33 ppm); and 4) RON 92 (0.46 ppm).

Based on the graph in Figure 3(b) regarding Fuel Type vs. Average HC Concentration in vehicles with a cylinder capacity of 1,373 cc, the highest HC concentrations are when using RON 88 and RON 90 fuels, with an average HC concentration of 13.93 ppm, and the lowest at the use of RON 92 fuel, with an average concentration of HC of 2.66 ppm. The ranking based on the lowest to highest average concentration of HC is: 1) RON 92 (2.66 ppm); 2) RON 98 (10.73 ppm); 3) RON 88 and RON 90 (13.93 ppm).

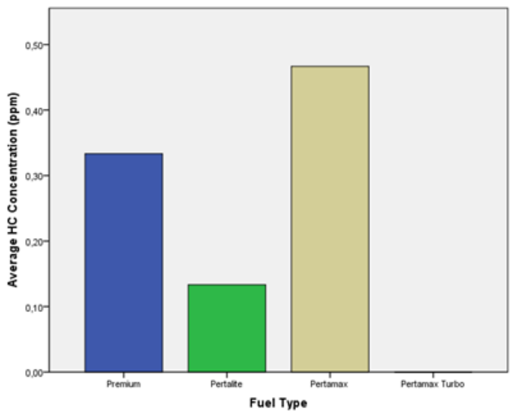

Figure 3(a). HC vs RON (1.198 cc)

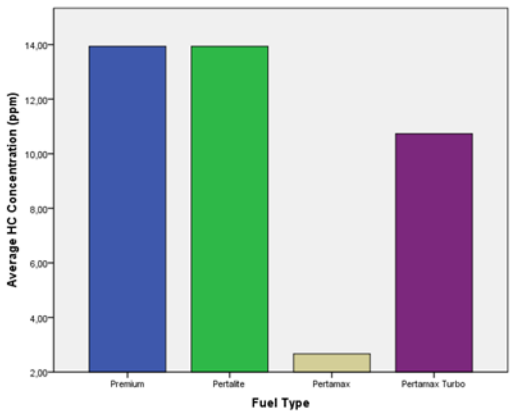

Figure 3(b). HC vs RON (1.373 cc)

Based on the latest emission limit regulations, Minister of Environment Regulation Number 8 of 2023, the emission limit for category M vehicles for the 2007-2018 manufacturing year is 1% for carbon monoxide (CO) and 150 ppm for hydrocarbons (HC). The concentrations of CO and HC produced from the vehicles tested were still below the emission limit. A comparison of combustion emissions with standard emission limits can be seen in Table 3.

Table 3. Comparison of vehicle emission limits.

Octane Number	cylinder capacity		Regulation No. 05 of 2006	Regulation No. 08 of 2023
	1.198cc	1.373cc		
carbon monoxide (CO) %				
88	0.0053	0.033	1,5	1
90	0.0033	0.026		
92	0.0013	0.014		
98	0.0026	0.05		
hydrocarbon (HC) ppm				
88	0.33	13.93	200	150
90	0.13	13.93		
92	0.46	2.66		
98	0	10.73		

Based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.20 of 2017 concerning quality standards for exhaust gas emissions for new types of motorized vehicles (implementation of the EURO 4 standard), it is stated that the emission test measurement methods and procedures are carried out using the ECE R 83-05 method (Economic Commission for Europe) and Test Mode (vehicle/engine operational conditions that must be met in emissions testing). This method will produce emission units in the form of grams per kilometer. This method is different from the method used in this research (SNI) 09-7118.1-2005, so comparisons cannot be made.

3.2. CO2 Concentration Measurement Results

Based on the graphs in Figures 4(a) and 4(b), the RPM Line Graph vs. the Average CO_2 Concentration for each type of fuel indicates the combustion process that occurs for each fuel trial at variations in engine speed running well (CO_2> 12%). CO2 concentration can be a direct benchmark for the status of the combustion process in the combustion chamber. When the AFR is at ideal numbers, the volume of CO_2 exhaust emissions will range from 12% to 15% (Rajagukguk, J., 2018 and Bridhe Analyzers, Inc, 2022). If the AFR is too poor or too rich, then the concentration of CO_2 emissions will decrease (Hillier, V., 2012). If CO_2 is below 12%, then other exhaust emissions will show an increase.

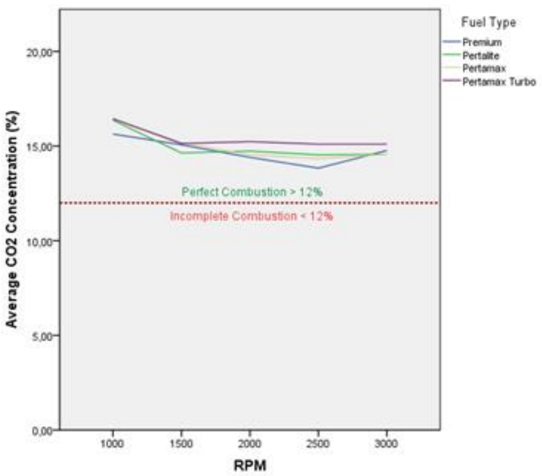

Figure 4(a). CO_2 vs RPM (1.198 cc)

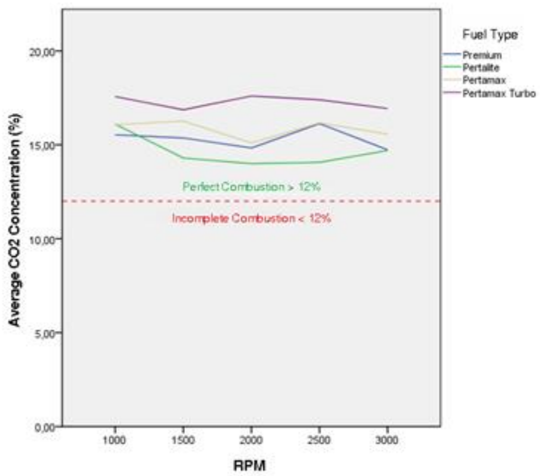

Figure 4(b). CO_2 vs RPM (1.373 cc)

Considering the HC concentration, the CO2 concentration is also correlated with the CO concentration. CO2 is the result of complete combustion between HC and O2. If the CO concentration is high, the fuel (HC) will burn, but not completely. This incomplete combustion can be caused by an imbalance in the fuel-air mixture during combustion. The balance of the fuel and air mixture is called AFR (Air Fuel Ratio). When completely burned, this gasoline-like fuel has an AFR of 14.7. However, in practice, the combustion reaction of AFR 14. 7 is rarely seen. A high CO concentration indicates a high AFR. Rich AFR occurs when the AFR value is less than 14.7 (if the amount of fuel in the combustion chamber is greater than the amount of air needed). Lean AFR, on the other hand, occurs when the AFR value exceeds 14.7 (when the amount of air in the combustion chamber is greater than necessary) (McAfee, 2002).

3.3. O2 Concentration measurement results

Based on the graphs in Figures 5(a) and 5(b), the RPM bar graph vs. the average concentration of O_2 in each type of fuel shows the combustion process that occurs in each fuel experiment at variations in engine speed running normally (O_2<1%) (Bridhe Analyzers, Inc, 2022). Poor engine combustion occurs when the fuel-air mixture is lean. Poor combustion causes a misfire condition which results in a high O_2 content in the exhaust gas (Hillier, V., 2012). The highest concentrations of O_2 occurred in trials using RON 88 fuel (1,198cc) and RON 90 (1,373cc) with an average O_2 concentration of 0.108% and 0.07%.

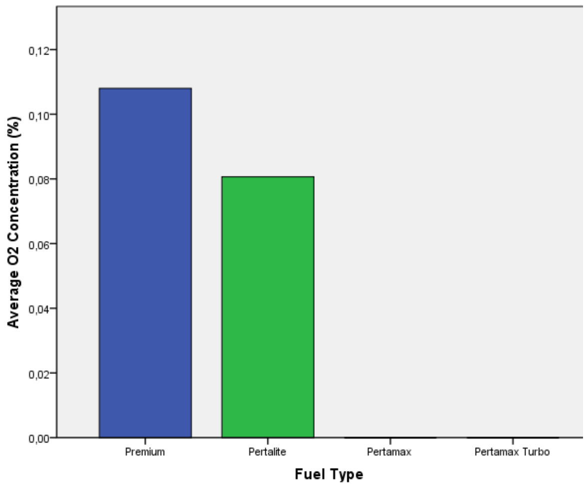

Figure 5(a). O_2 vs RON (1.198 cc)

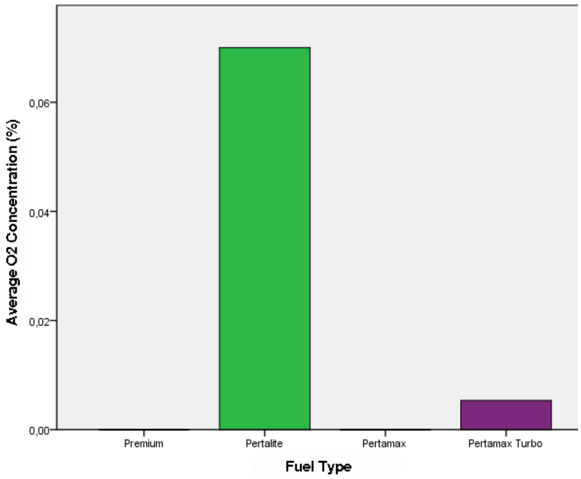

Figure 5(b). O_2 vs RON (1.373 cc)

Based on the theory and data obtained from the trials above, an increase in the fuel octane number causes a decrease in the concentration of CO and HC exhaust emissions because the use of fuel with the highest octane number will be more resistant to pressure so that it does not spontaneously burn or (knock) has an impact on vehicle performance and efficiency (Ariawan et al., 2016). However, if the octane value of the fuel used is too high from the recommended standard for the required fuel octane value (as seen in the highest average CO concentration in RON 98 fuel in the 1.373cc test vehicle), it will cause an ignition delay so that combustion efficiency decreases (Sayin, C., 2012). Although most of the decrease in the average concentration of CO and HC emissions occurs when using high-octane fuel, RON 92 fuel experiences the highest concentration of HC in vehicles with a capacity of 1,198 cc. This is due to the addition of new fuel due to the process of increasing power at 3000 rpm, so that complete combustion is

To reduce CO concentrations, based on research (Prayogi Y et al., 2019) adding a mixture of wet acetone and methanol to gasoline can improve EFI engine performance because oxygen levels in wet methanol and acetone can reduce the levels of HC and CO formed and increase O_2 and CO_2 levels.

In addition, another method that can be used to reduce CO emissions from vehicles is to mix fossil fuels with biomass fuels, as in research (Winangun K et al., 2020), a mixture of 80% Pertamax with 20% P100 (pure plastic oil) produces 4.33% CO. Meanwhile, the use of used cooking oil from sunflower oil and corn oil as a mixture of fossil fuels can reduce CO and HC levels because the presence of oxygen atoms in their chemical structure improves the combustion process and provides complete combustion (Kurji, H et al., 2018).

4. Conclusions

The use of various types of fuel at the same time as variations in engine speed show an effect on the concentration of HC and CO emissions released, where an increase in fuel octane number causes a decrease in the concentration of CO and HC exhaust emissions. An effective type of fuel that can be applied to vehicles with an EFI fuel delivery system with a compression ratio of 1: 10/10.2 and a cylinder capacity of 1,198cc–1,373cc is the type of fuel with RON 92 (Pertamax). When using higher-octane fuels such as RON 98, there is a higher increase in CO and HC emissions at low engine speeds.

Emissions released from all gasoline vehicles can be reduced effectively through electronic fuel injection and catalytic conversion mechanisms. However, this mechanism can work well when using gasoline with the appropriate octane number. It is best for the public to know how to use fuel according to the design capacity or compression ratio of their vehicle's engine because this can help improve the performance and efficiency of engines that have been designed to minimize emissions. The type of gasoline and compression ratio can be found in the user manual of each vehicle brand.

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