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The Effect of the Number of Injector Holes and Fuel Octane Number on Motorcycle Engine Exhaust Gas Emissions

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Abstract *An increase in the number of vehicles should also be accompanied by improvements in technology that can increase engine efficiency and at the same time reduce air pollution. This research aims to determine the effect of using variations in the number of holes in the injector and the octane number of the fuel on exhaust emissions in motorcycle engines. The research method uses experiments with descriptive analysis. The independent variable is the number of holes in the injector, 4, 6, and 8 and the octane number of 90, and 92. In the exhaust emissions testing process using engine speeds of 1000 rpm, 2000 rpm and 3000 rpm. The bound variable is the emission of carbon monoxide (CO) gas and hydrocarbon gas (HC). Data from CO and HC gas emission testing results at 1000 rpm are all still within the permitted limits. Furthermore, statistical analysis shows that there is an influence of the number of holes in the injector and the octane value of the fuel on CO and HC exhaust emissions and there is no interaction between the octane value variables and the number of injector holes on the CO and HC exhaust gas values. The best results are CO gas emissions = 0.55% and HC = 66 ppm when using a 6 holes injector (standard) and using fuel with an octane value of 92.*

Keywords *Injector Hole, Octane Rating, Exhaust Emissions, Carbon Monoxide, Hydrocarbons*

1. INTRODUCTION

Increasing demand for motorcycles among the public significantly influences the automotive industry's patterns to compete in producing high-quality products favored by consumers. Advances in automotive technology align with the rising preferences and standards of consumer desires. The fuel injection system in gasoline engines is one such technology that enhances engine performance and fuel efficiency . Besides, fuel injection system could reduce emission gases which are becoming serious global pollution problem and provide sufficient power to run the engine.

The injector is a key component of the fuel system, functioning to spray and atomize fuel into the intake manifold or combustion chamber. The smaller the fuel particle size, the easier it is for the fuel to mix homogeneously with air, thus improving engine performance. While the higher particle size results incomplete combustion, which produce more carbon monoxide (CO). Carbon monoxide (CO) and hydrocarbon (HC) exist in emission resulting from fossil fuels commonly used in Indonesia. Good engine performance is also assessed by the exhaust emissions produced, as efficient combustion can generate maximum power and torque while minimizing emissions of carbon monoxide (CO) and hydrocarbons (HC).

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The injector has holes at its tip, serving as fuel outlets. The efficiency of fuel spraying is influenced by several parameters, including spray pressure, the precision of the fuel-to-air ratio, and the number of holes in the injector.

Additionally, fuels with varying octane ratings (RON) affect their combustibility. Fuels with higher octane rating number have strong resistance to engine knock. Therefore, the higher the octane number, the harder it is to ignite, requiring higher compression pressure or compression ratios. Based on this theory, this study examines the variable number of injector holes, namely 4, 6 (standard), and 8 holes, as well as the variation in fuel octane ratings, specifically RON 90 (Pertalite) and RON 92 (Pertamax). Performance tests were conducted to measure engine performance and exhaust emissions, particularly CO and HC gases, based on engine RPM.

Carbon monoxide is one of the most abundant types of emission gases produced by motor vehicles, accounting for 76.4% of emissions. The concentration of carbon monoxide emissions in the air within a day is influenced by the activity of motor vehicles. The busier the traffic, the higher the emissions produced. Cities with heavy traffic generate relatively high levels of carbon monoxide, which can adversely affect health. A significant portion of the unintentional poisonings and fatalities that are recorded worldwide each year are caused by carbon monoxide.

2. REVIEW

Exhaust Gas Emissions

Emissions from the combustion of fuel and air (oxygen) that leave through the exhaust manifold are known as exhaust gas emissions. The product will be carbon dioxide (CO_2) gas and water vapor (H_2O) if the combustion process is flawless or optimum. After cooling, the H_2O will condense into water, and plants require CO_2 to assimilate into the oxygen (O_2) gas that humans require. However, some will become air pollutants including hydrocarbons (HC), NOx gasses (NO; NO_2; N_2O), and carbon monoxide (CO) gas if the combustion process is not flawless. Fuel and an oxidizer, such as oxygen or air, combine chemically during combustion to produce heat and light. An alternative definition of combustion is the chemical reaction of fuel and oxygen in the presence of an external energy source, known as activation energy. The fuel's bonds are broken by this energy, producing extremely reactive radicals (ions). In order to create stronger connections, the ions will react with oxygen. The system's temperature will rise as a result of the extra energy released during bond formation. The optimal combustion formula is:

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$$CnHm + (n+\frac{1}{4} m) O_2 \rightarrow n.CO_2 + \frac{1}{2} m.H_2O \quad (2\text{-}1)$$

The concentration of air based on volume is generally: N_2 = 79% and O_2 = 21%; The concentration of air by weight is: N_2 = 76.7% and O_2 = 23.3%; the air-to-oxygen weight ratio is 100:23.3 = 4.29.

The combustion process of hydrocarbons simply involves a mixture of fuel and oxidizer, producing combustion products as in (2-2). The most commonly used oxidizer is air, as it is available in unlimited quantities. In perfect combustion reactions, the fuel compounds react with the oxidizer, with products being part of the elements from both the fuel and oxidizer as follows:

$$2C_6H_6 + 15O_2 \rightarrow 12CO_2 + 6H_2O + \text{Heat} \quad (2\text{-}2)$$

The chemical reaction of fuel combustion with oxygen (benzene or gasoline) that occurs perfectly results only in emissions of CO_2 and H_2O. The air-fuel ratio (AFR) = 14.7, assuming that the oxygen content in the air is 21%. Combustion can occur if three main conditions are met: the presence of fuel, air (oxygen), and heat (spark ignition). Additionally, for optimal combustion, three more conditions are necessary: the appropriate fuel and air composition, a homogeneous mixture of air and fuel, and enough combustion time or proper timing adjustment.

Carbon monoxide (CO) gas results from the combination of carbon and oxygen, where this combination is insufficient to form CO_2. Carbon monoxide is produced by incomplete combustion caused by insufficient oxygen in the combustion process (rich composition or AFR < 14.7). The formation of CO is represented by the following reaction:

$$C + \frac{1}{2} O_2 \rightarrow CO \quad (2\text{-}3)$$

CO is a gas that does not easily dissolve in water, with a weight ratio to air (1 atm at 0°C) of 0.967, and when exposed to fire in air, it burns with blue smoke, turning into CO_2. The effect of CO is that it binds to hemoglobin (HB) with a greater affinity than oxygen, reducing the oxygen-carrying capacity of the blood, interfering with the central nervous system, and at high concentrations for a prolonged time, CO can cause unconsciousness and death. The cause of CO formation is primarily due to unburned or incomplete combustion of fuel.

$$C_6H_6 + 6O_2 \rightarrow 3H_2O + 3CO_2 + 3CO + \text{Heat} \quad (2\text{-}4)$$

The combustion reaction of benzene (C_6H_6) with oxygen (O_2) that can generate CO gas is shown in (2-4) with an air-fuel ratio (AFR) = 11.7 (slightly rich composition) assuming that the oxygen content in the air is 21%. The percentage of CO in exhaust emissions will be high at idle engine speeds and will decrease as the engine speed increases, stabilizing at constant engine speed. Excessive CO can lead to the formation of carbon deposits on valves, combustion chambers, piston heads, and spark plugs. These deposits naturally cause a phenomenon known as self-ignition and accelerate engine wear.

Hydrocarbon gas is a chemical compound consisting of only carbon (C) and hydrogen (H), it has a smell and is volatile. If it reacts further with NOx, it forms photochemical compounds that can damage the ozone layer. Hydrocarbons can cause eye irritation, sore throat, and trigger asthma attacks. Aromatic hydrocarbons and derivatives such as aldehydes are carcinogenic and can lead to cancer. The primary cause of hydrocarbon emissions is poor ignition system performance, such as damaged coils, distributors, or spark plug wires. Incorrect spark plug gap/electrode damage and overly advanced spark timing can also be causes. It can also be caused by a very rich composition or by non-homogeneous fuel-air mixtures due to leaking injectors or excessively long injector opening durations. In (2-5), the air-fuel ratio (AFR) = 7.3 (very rich composition) assuming that the oxygen content in the air is 21%.

$$4C_6H_6 + 15O_2 \rightarrow {}_6H_2O + 12CO_2 + 12HC + Heat \ (2\text{-}5)$$

In (2-6), which produces both HC and CO exhaust emissions, the air-fuel ratio (AFR) = 7.8 (very rich composition), assuming that the oxygen content in the air is 21%.

$$C_6H_6 + 4O_2 \rightarrow 2H_2O + 2CO_2 + 2HC + 2CO + Heat \ (2\text{-}6)$$

NOx gases are primarily in the form of NO, NO_2, and N_2O. NO is colorless, odorless, poorly soluble in water, and reacts further with air to become NO_2. NO_2 is reddish and slightly odorous, soluble in water, and reacts with water to form nitrous/nitric acid. NOx reacts with hydrocarbons to produce ozone pollutants. The impact of NO is hemotoxic (binding to red blood cells), causing central nervous system disturbances, throat, eye, and nose irritation, and its toxic properties cause difficulty sleeping, coughing, etc. (at concentrations of 30-50 ppm).

$$N_2 + O_2 \rightarrow 2NO \text{ or}$$

$$N_2 + 2O_2 \rightarrow 2NO_2 \ (2\text{-}7)$$

Injector

An injector is an electromagnetic device that injects fuel based on the signals received from the Electronic Control Unit (ECU). The injector sprays gasoline into the throttle body. When the signal from the ECU reaches the solenoid coil, the plunger is pulled against the spring force, and gasoline is injected. The volume of fuel injected depends on the pressure and the duration of the signal received to open the nozzle sent by the ECU.

A Pressure Regulator is a device in the PGM-FI fuel delivery system that regulates the fuel pressure in the fuel line, which delivers fuel to the injector. The pressure in the line is 294 kPa (3.0 kgf/cm^2, 43 psi). If the pressure exceeds 294 kPa (3.0 kgf/cm^2, 43 psi), the fuel will return to the tank. Injector specifications based on research [8].

Table 1 Injector Specifications

Injector Specifications	Injector Types		
	4 lb	6 lb	8lb
Debit [cc/menit]	50	49	50
Hole Diameter [mm]	0,16316	0.13190	0,11538

Source: Fahregi, 2023 [8]

The difference in flow rates in this type of injector will affect the AFR, because the ECU has been programmed according to the fuel pressure value and the standard injector hole count, thus regulating the fuel flow based on the injector opening duration according to the engine's needs. The flow data and hole count, based on calculations, also indicate that the diameter of the injector holes is not the same, and this will affect the droplet size coming out of the injector, as illustrated in Figure 1 If the diameter becomes smaller, the area of the liquid core will also be smaller, so the formation of droplets in the primary and secondary breakups will occur more quickly, and vice versa.

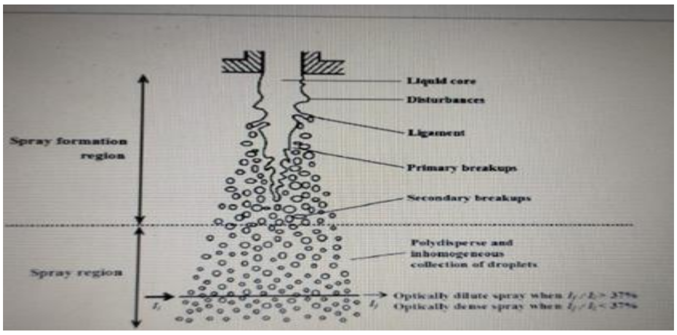


Figure 1

Based on Table 1, injectors with 4 holes have a larger hole diameter and a slightly higher spraying volume compared to injectors with 6 holes (standard injectors). This means that the use of injectors with 4 holes will result in higher CO and HC gas emissions compared to using standard injectors (injectors with 6 holes), because the larger injector holes will produce slightly larger droplets, thus the fuel-air mixture will be less homogeneous, which will cause an increase in HC exhaust gas emissions. The slightly higher spraying volume can lead to a slightly richer air-fuel ratio (AFR), which can increase CO exhaust gas emissions.

In the case of using an injector with 8 holes, based on the slightly higher spraying volume (50 cc/min) but with slightly smaller hole diameters (0.11538 mm), it is possible that the CO gas emissions will slightly increase, while the HC gas emissions will be relatively better or the same. This analysis refers to the condition where the ECU program settings remain unchanged, but if the ECU program can automatically adjust, the emission results will always be good or always below the standard.

Octane Rating

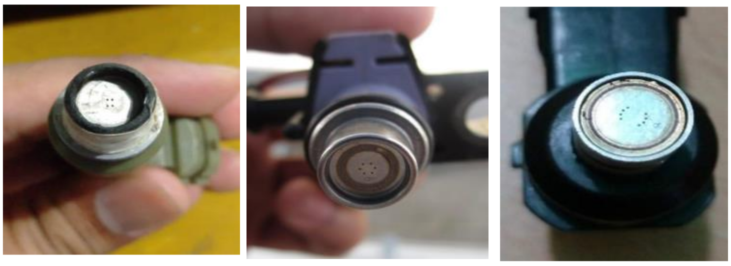
The octane number is a figure that indicates how much pressure can be applied before gasoline fuel spontaneously ignites. Inside the combustion chamber, the air-fuel mixture (in gas form) is compressed by the piston until the volume is very small and then ignited by a spark from the spark plug. The high pressure in the combustion chamber can cause the air-fuel mixture to ignite spontaneously before the spark plug spark is released. This condition will cause knocking or pinging inside the engine. Knocking will damage the engine quickly, so it should be avoided as much as possible. The name octane comes from octane (C8) because among all the molecules that make up gasoline, octane has the best compression properties. Octane can be compressed to a small volume without experiencing spontaneous combustion, unlike heptane, for example, which can ignite spontaneously even when slightly compressed. Premium fuel has an octane number of 88, while Pertalite has an octane number of 90, Pertamax is 92, and Pertamax Plus is 95. This number indicates how much pressure can be applied before gasoline ignites spontaneously. The higher the octane number, the slower the gasoline burns, thus leaving less residue in the engine that could affect its performance. High-octane fuels are suitable for vehicles that use high compression. Fuel with an octane rating of 95 has a better ability to reduce carbon residue deposits and can make combustion more perfect. The octane number indicates the percentage volume of iso-octane in gasoline. Gasoline that contains a lot of straight-chain hydrocarbons, such as n-heptane, burns very easily in the engine, causing knocking sounds, which can lead to engine damage.

3. MATERIAL AND METHODS

Material and Equipments

The materials used in this research include:

a) Fuel with an octane rating of 90 (pertalite) and an octane rating of 92 (pertamax)



4 Holes 6 Holes 8 Holes

Figure 2 Injector types

b) Equipment

1. Injector with 4, 6, and 8 holes
2. 2017 Honda Beat motorcycle
3. Gas Analyzer
4. Measuring cup
5. Tachometer
6. Tools set

Research Variable

This study has two variables, namely the independent variable and the dependent variable. The independent variables are: the number of injector holes (4, 6, and 8) and the octane rating of the fuel (90 and 92). The dependent variables are: the emissions of carbon monoxide (CO) and hydrocarbons (HC).

The Stages of the research

The stages of the research implementation are as follows:

1) Conduct a test using standard injector types (6-hole injector) and fuel with an octane rating of 90 (Pertalite).

2) Compare the emission test results of CO and HC with the environmental ministry's standard regulations.

3) If the test results do not meet the specifications of the engine used, perform repairs or tune up the engine until the results match the specifications.

4) Once the test is considered sufficient, replace with a 4-hole injector and then with an 8-hole injector.

5) Replace the fuel from Pertalite to Pertamax.

6) Conduct another test using fuel with an octane rating of 92 (Pertamax) for the 8-hole injector.

7) Repeat step 6 with the 4-hole and 6-hole injectors.

8) Perform data analysis using statistical analysis of two variables to determine if there is any influence from the number of injector holes and the octane rating of the fuel.

9) Create a graph showing the relationship between the number of injector holes, octane rating, and the emissions of CO and HC, if the statistical analysis shows any significant influence.

4. RESULTS AND DISCUSSION

Data Analysis

Based on the research data, a statistical analysis can be performed to determine whether there is an effect of the number of injector holes and the octane rating on the emissions of CO and HC.

Table 2 CO gas emissions at 1000 rpm

Number of holes	Octane 90			Octane 92
	CO %	HC ppm	CO %	HC ppm
4	0,95	95	0,55	90
	0,89	94	0,75	91
	0,90	85	0,65	85
Average	**0,91**	**91**	**0,65**	**89**
6	0,55	65	0,55	55
	0,65	70	0,60	60
	0,60	75	0,50	65
Average	**0,60**	**70**	**0,55**	**60**
8	0,79	95	0,58	61
	0,89	94	0,66	66
	0,85	85	0,56	68
Average	**0,84**	**91**	**0,60**	**65**

Next, the CO gas emission data at low rpm in Table 2 is analyzed using variance for two-way classification, a fixed-effects model, with statistical calculations resulting in the outcomes as shown in Table 2.

Table 3 The results of the statistical analysis calculations for CO gas at low RPM (±1500 rpm).

Source Variant	Square Number	Degree of Freedom	Square Average	F_o ($F_{calculated}$)	F_{table}
The number of holes	0,134	2	0,067	13,231	$F_{0,05;2;12}$ = 3,89
Octane Number	0,038	1	0,038	7,579	$F_{0,05;1;12}$ = 4,75

Interaction	0,007	2	0,004	0,727	$F_{0,05;2;12}$ = 3,89
Error	0,061	12	0,005	-	-
Total	0,210	17	0,014	-	-

Based on the results of the statistical analysis, the following preliminary conclusions can be drawn:

1. The number of injector holes significantly affects the CO gas emission values, as Fo (Fcalculated) > Ftable (13.231 > 3.89).
2. The octane value also significantly affects the CO gas emission values, as Fo (Fcalculated) > Ftable (7.579 > 4.75). The type of injector used in the engine can be adjusted according to the requirements so that the CO gas emission does not exceed the specified limit.
3. There is no interaction between the number of injector holes and the octane value, as Fo (Fcalculated) < Ftable (0.727 < 3.89). Therefore, the type of injector used in the engine can be adjusted by considering the octane value of the fuel to achieve the lowest CO gas emission value or to meet the specified limits.

Graphic Analysis

Figure 3 The effect of the number of injector holes and the fuel octane value on CO gas emissions

In Figure 3, it can be seen that the number of holes in the injector significantly affects the CO gas emissions, both when using fuel with an octane value of 90 and 92. The injector with 6 holes produces the lowest CO gas emission values, which are 0.55% when using fuel with an octane value of 92, and 0.6% when using fuel with an octane value of 90. One of the causes of high CO gas emissions during the combustion process is the relatively rich AFR, or the higher fuel content compared to the standard AFR condition. This is consistent with the fuel spray rate or volume data per unit time in Table 2.1, which shows that the injector with 6 holes has the smallest flow rate (49 cc/min).

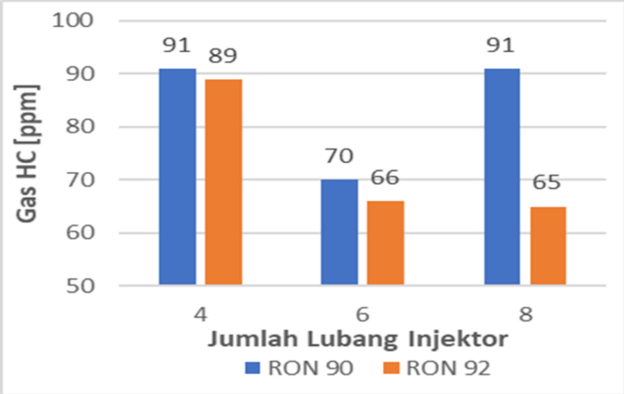


Figure 4 The effect of the number of injector holes and fuel octane value on HC gas emissions

In Figure 4, it can be seen that the number of holes in the injector significantly affects the HC gas emission values, both when using fuel with an octane rating of 90 and 92. The injector with 6 holes produces the lowest HC gas emission values, which are 66 ppm when using fuel with an octane rating of 92, and 70 ppm when using fuel with an octane rating of 90. The combustion process that generates high HC gas emissions is partly caused by a relatively rich AFR and a non-homogeneous mixture. This is consistent with the flow data in Table 2.1, where the injector with 4 holes has slightly larger hole diameters, which can lead to a non-homogeneous fuel and air mixture.

5. CONCLUSION

Based on the discussion results, the research findings can be concluded as follows:

1. There is an effect of the number of injector holes on CO and HC exhaust gas emissions. The injector type with 6 holes produces the best CO and HC exhaust gas emission values for all fuel octane ratings.
2. There is an effect of fuel octane rating on CO and HC exhaust gas emissions in gasoline engines. Fuel with an octane rating of 92 is the best for all types of injectors.

6. LIMITATION

The study is limited to evaluating the impact of the number of injector holes and fuel octane value on CO and HC emissions in motorcycle engines, without considering other potential factors that may influence exhaust emissions.

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