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Analysis of the Effect of Fuel System, Fuel Types and Spark Plug Types on CO_2 Gas Exhaust using Factorial Design

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Abstract---*The vehicle combustion system, the type of fuel used and the type of spark plugs, are some of the variables that affect motor vehicle exhaust gases. Some exhaust gases (pollutants) by motorized vehicles include Carbon Dioxide (CO2), Carbon Monoxide (CO), Sulfur Dioxide (SO2), Nitrogen Monoxide (NOx), Hydrocarbon (HC), and Lead, smoke and ash, where Exhaust gas can pollute the air and greatly affect human health. From a number of variables that influence motorized exhaust gas, the author determines the combustion system variable, namely the Carburetors and EFI types, the fuel variable type is Premium (octane 88) and Pertamax (octane 92), as well as the spark plug type variable and Iridium spark plugs, as variables main effect to analyze CO2 exhaust gas. The motorized vehicle used as a trial is a 4-step duck motorcycle, 110 cc. The test equipment used to analyze exhaust gas is the Kane Gas Analyzer (Class1). The research method used is factorial design and variable analysis using Yates' Algorithm, the same as in the previous experiment [1]. Yates's Algorithm Analysis results that the effect of CO2 exhaust is the greatest due to the fuel system of 1.117 (EFI), the second effect is the type of fuel of 0.450 (Pertamax), and the third effect is the type of spark plug of -0.050 (standard spark plug).*

Keywords---*Carburetor, Gas Analyzer, CO2, Factorial design.*

I. INTRODUCTION

The combustion system, the type of fuel and the type of ignition, are important variables for 4-step motor vehicles, especially those with gasoline. The use of EFI technology (Electronic Fuel Injection) on the fuel supply system into the combustion chamber using injection electronics, is to produce good efficiency from the carburetor system (Anwar,A., 2019). Changes in the combustion system have the effect of exhaust gas from combustion, including Carbon Dioxide (CO2), Carbon Monoxide (CO), Sulfur Dioxide (SO2), Nitrogen Monoxide (NOx), Hydrocarbon (HC), and others.

Technological developments not only on the vehicle engine, but also on the types of fuel, including premium fuels (octane 88), Pertalite (octane 90), Pertamax (octane 92), Pertamax Plus (octane 95) and Pertamax Turbo (octane 98), is aimed at increasing vehicle efficiency and being friendly to the environment. All changes will have an impact on vehicle exhaust.

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In general, vehicle exhaust gases pollute the air and in a certain amount will harm human health.The health effects that are often encountered are ARI, namely (acute respiratory infections) due to vehicle pollution. Other impacts are asthma and bronchitis. Some pollutants are included as toxic (toxic) and carcinogenic (causing cancer).

The community needs to be educated about the effect of vehicle exhaust on health. With this knowledge people can use vehicles wisely.

II. FUEL SYSTEM

There are 2 important parts in the fuel system, namely fuel supply and fuel gauge. Broadly speaking, the supply of fuel is flowing fuel from the tank to the fuel gauge.

Function of the fuel gauge system:

- Adjust the amount of mixture of air volume and fuel volume to get the right mixture, so that air and fuel can be burned quickly and perfectly in the combustion chamber.
- Atomizing and spreading fuel in the air flow, also known as Air Fuel Ratio (AFR).

Air Fuel Ratio (AFR) is a ratio of the amount of air to fuel in weight. Theoretically, the ratio of the perfect combustion process or also called stochiometric AFR for the otto motor is 14.7. Air and fuel comparison depends on the engine operating conditions needed in the cylinder chamber. For example, in the initial starter (cold), it requires a mixture that is rich in fuel. In the condition that the engine is still cold, the fuel that evaporates is only partially so that additional fuel is needed to obtain a mixture that is ready to be burned in the cylinder. The carburetor has been widely used in almost all 4-step iron engines. But with the advancement of technology and the development of the era, more efficient carburetors and exhaust gases are needed more environmentally friendly, so that more complicated additional tools are needed.

Carburetor replacement system is needed, namely the EFI (Electronic Fuel Injection) fuel system. The EFI system is injecting fuel into the combustion chamber electronically.

Setting the volume and duration of the fuel injection and adjusting the ignition time are controlled by the ECU (electronic control unit). In the EFI system a sensors is installed on the machine to detect engine conditions. The sensor will convey data on the ECU regarding the amount of fuel needed to enter the combustion chamber, and EFI gives an order to the injector to provide pressure and duration of fuel in the combustion chamber. With EFI settings, the ratio of fuel and air will be efficient on all engine conditions.

Some differences in the carburetor and EFI systems are as follows:

a) How the fuel and air mixture works.
   - In the carburetor system, mixing fuel and air is caused by the vacuum of the combustion chamber due to the piston suction step. In the Carburetor system the ratio of fuel to air does not depend on the time and condition of the engine. The amount of fuel and air entering the combustion chamber depends on the suction capacity of the piston in the combustion chamber. When the engine starts, air flows in the carburetor chamber through the venture. Because there is a decrease, the fuel enters through the venture gap, so that the air mixes with the fuel and enters the combustion chamber during the suction process. The higher the rpm the greater the mixture's air and fuel speed.

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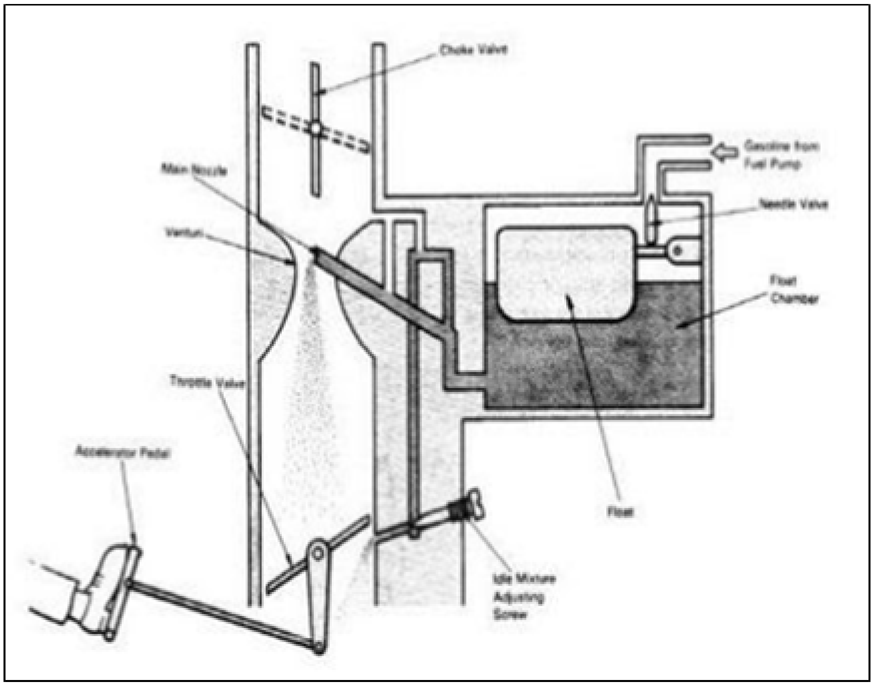

Figure- 1.*Carburetor system*

- In the EFI system, mixing fuel and air is done by the injector at the ECU's command. Where ECU gets data from sensors that have been installed.

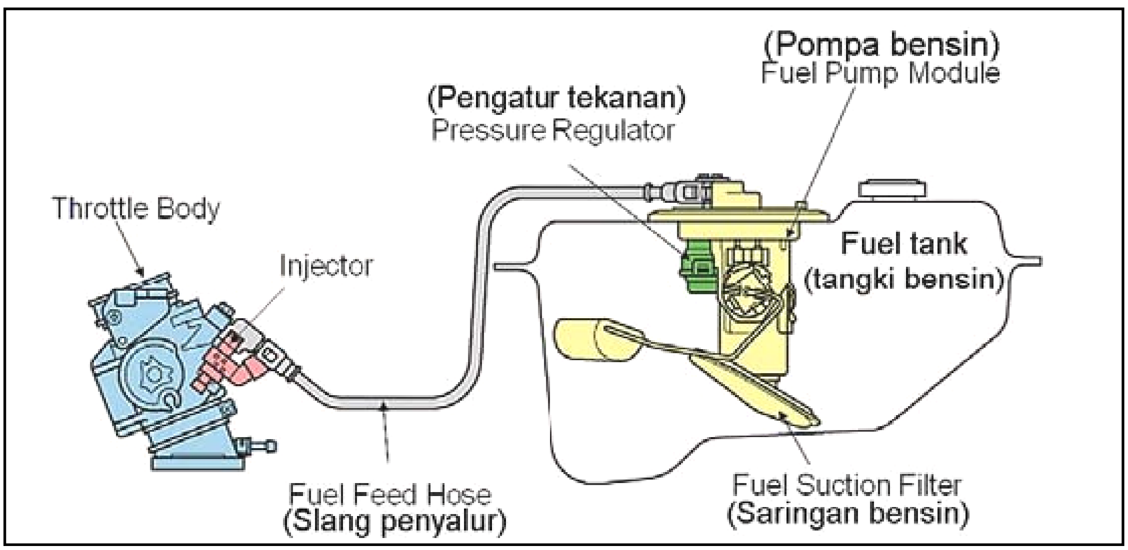

Figure 2:*EFI injection system*

b) Cold engine temperature conditions.

In conditions of cold engine temperature, to turn on the engine requires a mixture that is rich in fuel. So that different treatment is needed between the carburetor and EFI systems.

- In the carburetor system to enrich the fuel mixture, choke is used so that the fuel ratio becomes rich.
- In the EFI system, the temperature sensor will send a cold signal condition of the engine temperature to the ECU, then the ECU instructs the injector to enrich the fuel mixture.

c) Acceleration conditions.

In accelerated conditions, the engine requires a mixture of air and fuel around 8: 1 AFR.

- The carburetor system is assisted by an accelerator nozzle which functions to increase fuel supply to the combustion chamber when the rpm rises suddenly.

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- In the EFI system, the throttle position sensor will send to the ECU, and then the ECU processes the injector to increase the fuel mixture.

d) High Turn Conditions.

- In the system the carburetor, main jet and jet pilot are fully open to produce a large amount of power.
- In the EFI system, the throttle position sensor and vacuum sensor at the intake manifold send a signal to the ECU, then the ECU orders the injector to slightly enrich the mixture.

III. EXHAUST GAS EMISSIONS

Vehicle exhaust emissions are pollutants that pollute the air. Vehicle exhaust is the gas left over from the combustion process between air and fuel, which is discharged into the air through the vehicle's exhaust line.

There are several main emissions produced by vehicles, including Hydrocarbons (HC), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Carbon dioxide (CO2), Lead (Pb) and particles that emit from the exhaust gas.

a) Hydrocarbon compounds (HC) occur due to incomplete combustion, which is because the fuel has not been burned completely but has been wasted with the exhaust gas. There are 2 different Hydrocarbon Compounds (HC), first the unburned fuel so that it comes out to be raw gas, and second, because of the heat, the fuel turns into another HC group that comes out with the exhaust gas

$C_8H_{18} \rightarrow H + C + HC$ .... (1)

b) The temperature around the wall of the combustion chamber is low, while the heat produced by the spark plug in the combustion chamber moves very fast so that combustion in the combustion chamber is not perfect. This results in a mixture of fuel and air in the quenching zone, and then out into the exhaust line.

c) In the carburetor system, during engine brake, where the gas valve (throttle valve) closes while the engine speed is still high, causing a large and not completely burned fuel suction. The rich and abundant mixture of this fuel is not burned and wasted.

d) Overlapping (the inlet valve and removing all open) on the carburetor system is too long. So the HC functions as a rinse / cleaning gas that occurs at low speed. HC compounds affect human health, such as painful eyes, sore throat, lung disease and cancer. Graph of the relationship between air-fuel mixture and HC can be seen in Figure 3.

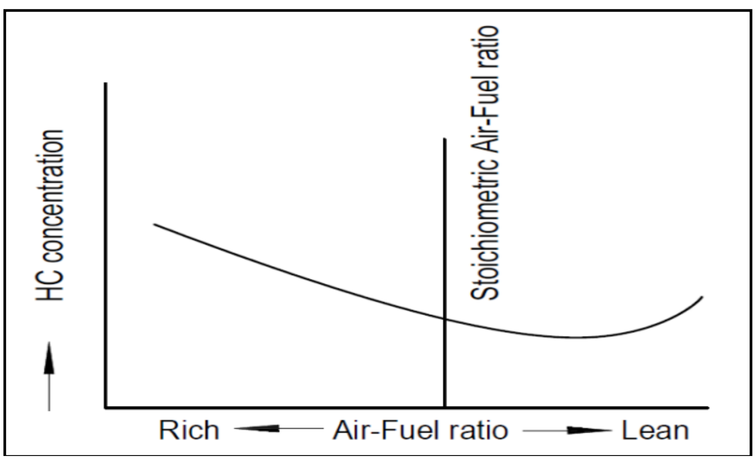

Figure3:*Relationship between Mixtures*

Air-Fuel and HC

e) Carbon monoxide (CO), occurs because of incomplete combustion. It can happen because the ratio of fuel and air is too much fuel (rich), so the fuel burns partially, or it could also be a lack of heating from ignition. Carbon combustion process in the combustion chamber is as follows:

$$2C + O_2 \rightarrow 2CO \quad (2)$$

Comparison of fuel mixtures, greatly affects CO gas combustion in the combustion chamber.Reducing the ratio of fuel to air made thin, can reduce CO gas. But this will have an impact on reduced power in the vehicle. CO is very dangerous for human health. Colorless or smelly CO gas, resulting in dizziness, nausea, breathing disorders, can even lead to death. Graph of the relationship between the mixture of air-fuel, CO and CO2 can be seen in Figure 4.

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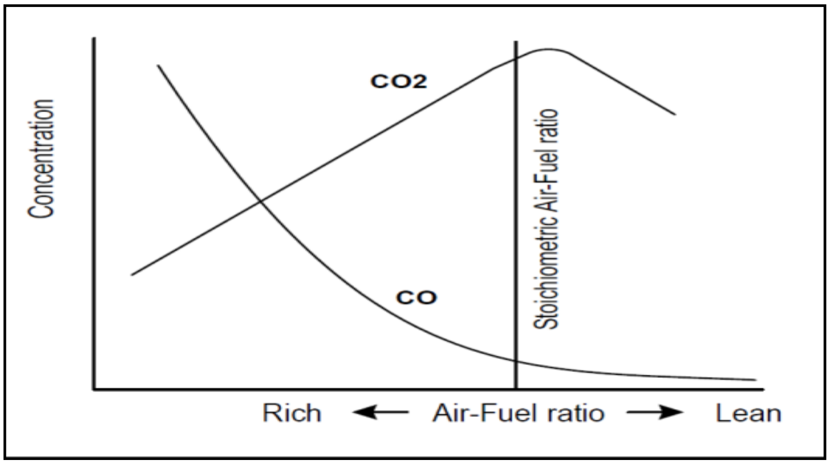

Figure 4: *Relationship Between Mixtures*

Air-Fuel, CO and CO2

IV. METHODOLOGY

This study uses the factorial design method and its analysis using the Yates' algorithm Method. This method has been applied in the previous study on CO gas [1].

a. Factorial Design

Research design needs to be done to determine the steps of the study involving several variables that influence the results of the study. Usually conventional experiments only measure one variable for one influence. In factorial design is to combine several variables in the same test, so as to reduce the number of experiments that are not needed.

IV.I. Basic Principles

Example: There are 3 variables that will be analyzed, for example T = Temperature, C = Concentration and K = Catalyst, each variable has 2 certain values "-" and "+" (Table-1). So the design factorial is $2^3 = 8$

Table 1:*Variable Value*

T, Temperature		C, Concentration		K, Catalyst	
-	+	-	+	-	+

For example, each variable has 2 ("-" and "+"), such as:

- Temperature, T = 160°C and 180°C
- Concentration, C = 20% and 40%
- Catalyst, K = types A and B

Then Table-1 becomes:

Table2:*Variable value (Result)*

Temperatur, T (°C)		*Concentration, C* (%)		*Catalyst, K*	
- 160	+ 180	- 20	+ 40	- A	+ B

By using factorial design, the experimental design that must be done is 8 times the variation of the experiment ($2^3 = 8$). (Table-3).

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Table3:*Experimental design*

No	T	C	K	Result
1	-	-	-	
2	+	-	-	
3	-	+	-	
4	+	+	-	
5	-	-	+	
6	+	-	+	
7	-	+	+	
8	+	+	+	

So by entering the variable value in each experiment, then table-2 becomes:

Table4:*Experimental design (result)*

Run Number	Temperature T (oC)	Concentration C (%)	Catalyst K	Result y (%)
1	160	20	A	60
2	180	20	A	72
3	160	40	A	54
4	180	40	A	68
5	160	20	B	52
6	180	20	B	83
7	160	40	B	45
8	180	40	B	80

b) Yates's algorithm

Yates's algorithm is a method for determining the main effects of each variable and the effect of the variable relationship. The next data processing is to determine the dominance of the influence of the variable relationships and the influence of each variable, which uses the Yates' Algorithm.

After the test results are obtained from the trial design (Table-4), then tabulated like figure-5.

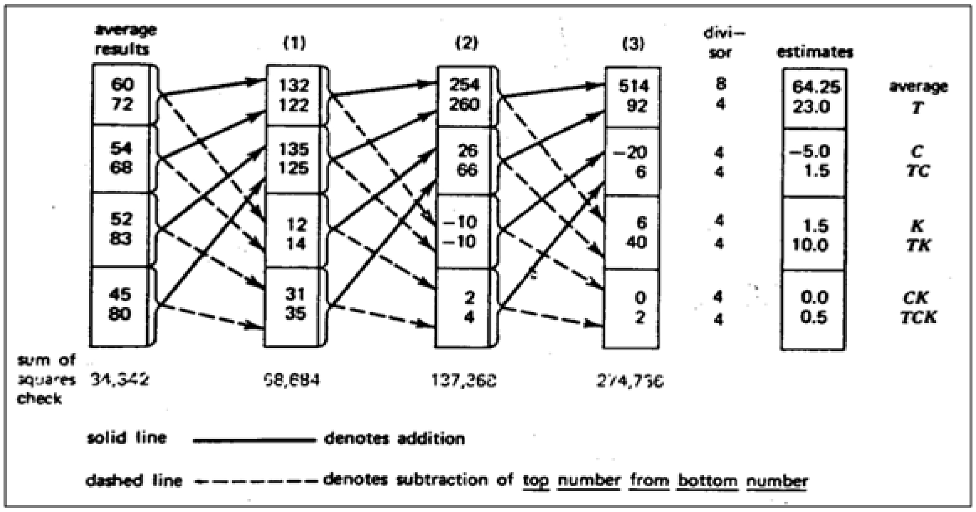

Figure 5:*Yates's Algorithm Tabulation*

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- Column 1. The average result of the experiment is placed in the column on the left (60, 72, 54 ... etc), and grouped. For example a value of 60 with 72, 54 with 68 .. etc.
- In column 2 (1), the value 132 is the sum of the value of 60 + 72, the value of 122 is the sum of 54 + 68, as well as the values of 135 and 125. This summing operation is indicated by a continuous arrow line. Next to the value 12 is a reduction from 72-60, as well as values 12, 14, 31 and 35. This subtraction operation is marked by a dashed arrow.
- For columns 3 (3) and 4 (5), the calculation uses the same pattern as column 1.
- Column 5, is the divider value
- The last column, is the value of the influence of the variable and combined variables.

The results of processing data using Figure 5, obtained the following results:

Influence:

Temperature (C)	= 23.
Concentration, C (%)	= -5.0
Catalyst, K (A or B)	= 1.5
Temperature (T) + Concentration (C)	= 1.5
Temperature (T) + Catalyst (K)	= 10.0
Concentration (C) + Catalyst (K)	= 0.0
T + C + K	= 0.5

From processing, the most influential sequence of variables is:

Individual effect

Variable Temperature = 23.0

Interaction effect

Variable Temperature + Catalyst = 10.0

V. EXPERIMENT

a) Experiment Design

The design of the experiment is based on the factorial design method, where there are 3 variables (fuel system FS, fuel type FT and spark plug type SPT) which are then determined by 2 testing limits ('-' and '+ '). Next, with the factorial design method, the number of experiments is:

Number of Experiments = 2^n,

Where, n = variable tested = 3

Then, trial = 2^3 = 8 Experiments

Table-5:*Initial design of the experiment.*

Fuel System		Fuel Type		Spark Plug Type	
-	+	-	+	-	+

So after plotting, Table-5 becomes:

Table-6:*Initial design of the experiment (after plotting)*

No	Fuel System	Fuel Type	Spark Plug Type	Result
1	-	-	-	
2	+	-	-	
3	-	+	-	
4	+	+	-	
5	-	-	+	
6	+	-	+	
7	-	+	+	
8	+	+	+	

Where for the testing limit values ('-' and '+ ') are as follows:

1. Fuel System

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"+" = Electronic Fuel Injection (EFI)
"-" = Carburetor (Carbu)

2. Fuel Type
"+" = Pertamax, octane 92 (92)
"-" = Premium, octane 88 (88)

3. Spark Plug Type
"+" = Iridium (IRD)
"-" = Standard (STD)

So that the initial experimental design becomes:

Table7:*Value design of the experiment*

fuel system		fuel type		spark plug type	
Carbu	EFI	88	92	STD	IRD

Then Table 6 becomes:

Table8:*Value design of the experiment (after plotting)*

No	fuel system	fuel type	spark plug type	Result
1	Carbu	88	STD	
2	EFI	88	STD	
3	Carbu	92	STD	
4	EFI	92	STD	
5	Carbu	88	IRD	
6	EFI	88	IRD	
7	Carbu	92	IRD	
8	EFI	92	IRD	

b) Experiment Process

Before conducting the experiment, good preparation is needed, in order to obtain results and avoid mistakes. Some activities must be prepared.

Preparation of vehicles to be tested:

– Preparation of test vehicle types
  Type : Motorized 4 steps SOHC
  Brand : Honda Scooter
  Power : 8.99 PS / 8000 rpm
  Transmission: Automatic, V-Matic
– Heating the motor to normal temperature and checking the test device (Gas Analyzer)
– Check for leaks in the exhaust gas system and test system.
– Idling rotation and ignition settings according to factory specifications.
– After the heating process, the rpm is raised to medium rpm for ± 15 seconds without load, then returns to the Idling cycle (/ - 1200 rpm).

Testing Process:

– After the process is heated, the next step is to install a gas sensor (gas probe) on the motor exhaust. Insert the gas sensor in the exhaust gas pipe as deep as 30 cm to avoid mistakes. Wait for ± 20 seconds until the data on the screen is stable.
– Record all test results.
– Perform further testing
– Perform testing for other variables.

VI. TEST RESULTS AND ANALYSIS

The following table-9 is the results of CO_2 exhaust testing (%):

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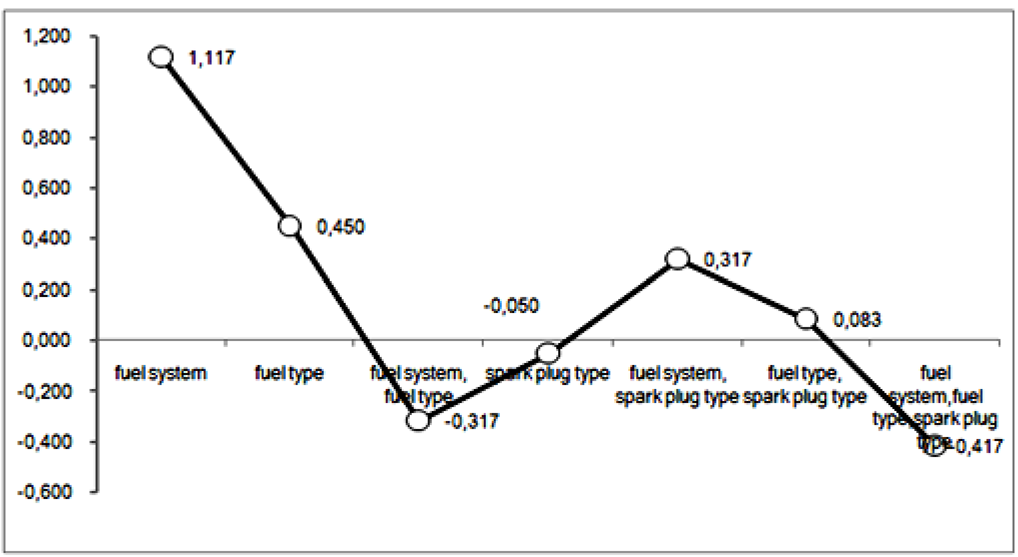
Table9:*CO2 Testing Results*

NO	fuel system	fuel type	spark plug type	Testing			Result Avg
				1	2	3	
1	CARBU	88	STD	3.30	3.20	3.20	3.233
2	EFI	88	STD	4.10	3.80	3.90	3.933
3	CARBU	92	STD	3.80	3.40	3.30	3.500
4	EFI	92	STD	4.40	4.40	4.40	4.400
5	CARBU	88	IRD	2.50	2.20	2.40	2.367
6	EFI	88	IRD	4.10	4.40	5.10	4.533
7	CARBU	92	IRD	3.30	3.90	3.70	3.633
8	EFI	92	IRD	4.30	4.40	4.30	4.333

To determine the effect of variables on CO2 exhaust gas, analysis using the Yates's Algorithm. Results can be seen in table 10.

Table10:*Results of the analysis using Yates' Algorithm.*

CO2 (%)	1	2	3	Devide	Estimasi (%)	Effect
3.233	7.167	15.067	29.933	8	3.742	Avg
3.933	7.900	14.867	4.467	4	1.117	fuel system
3.500	6.900	1.600	1.800	4	0.450	fuel type
4.400	7.967	2.867	-1.267	4	-0.317	fuel system, fuel type
2.367	0.700	0.733	-0.200	4	-0.050	spark plug type
4.533	0.900	1.067	1.267	4	0.317	fuel system, spark plug type
3.633	2.167	0.200	0.333	4	0.083	fuel type, spark plug type
4.333	0.700	-1.467	-1.667	4	-0.417	fuel system, fuel type, spark plug



Graph-1:*Variable Effect to CO2 gas*

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1) Fuel system variable = 1.117
   This shows that the effect of the fuel system on exhaust gases is 1.117. This is the largest value of all variables tested. The negative value (-) shows that 2 are variable values (‘-‘ = carburetor system and ‘+’ = EFI system), so the effect on the fuel system is EFI.
2) Variable type of fuel = 0.450
   This shows that the effect of the type of fuel on the exhaust gas is 0.450. Positive values (+) show that 2 values of fuel type variable (‘-‘ = Octane 88 premium and ‘+ 'pertamax Octane 92). So what affects the type of fuel is the Pertamax octane 92
3) Spark Plug Type Variable = -0,050
   This shows that the effect of spark plug type on the exhaust gas in this condition is -0.050. A positive value (-) indicates that 2 values of ignition variables (‘-‘ = STANDARD spark plugs and ‘+’ = IRIDIUM spark plugs). So the variable that most influences the Type of Spark Plug is the Standard Spark Plug.

VII. CONCLUSION

Yates’s Algorithm Analysis results that the effect of CO2 exhaust is the greatest due to the fuel system of 1.117 (EFI), the second effect is the type of fuel of 0.450 (Pertamax), and the third effect is the type of spark plug -0.050 (standard spark plug). So the most influential variable on CO2 gas production is the fuel system that uses EFI

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