Catalytic Converter based on Titanium Oxide (TiO_2) to Reduce the Emission of Carbon Monoxide and Hydrocarbon in Exhaust Gas of Motor Vehicles

Ahmad Mustamil Khoiron[1], Samsudin Anis[1], Masugino[1], Syahdan Sigit Maulana[1], Saian Nur Fajri[2]
[1]Department of Mechanical Engineering, Universitas Negeri Semarang, Semarang, Indonesia
[2] National Yunlin University of Science and Tecnology, Yunlin, Taiwan

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Abstract: Motor vehicle is a transportation which uses petroleum fuels as its energy resource. Crude oil as the raw materials processed into any kinds of petroleum fuels then used for the motor vehicle. Afterward, fuel is changed into mechanical energy through the combustion process which also produces the dangerous pollutant. Aimed to reduce the air pollution which has toxicity from internal combustion engine then used Catalytic Converter. However, Catalytic Converter has a high price and causing most gasoline vehicles did not fully use this technology. The case happened because catalytic made from Palladium, Platinum, and Rhodium. The breakthrough is made by making a ceramic-based catalyst with Titanium Dioxide additive. The purposes of the research are; (a) to know the reduction of carbon monoxide in the exhaust gas emission using Titanium Oxide (TiO_2), (b) to know the reduction of HC in the exhaust gas emission using Titanium Oxide (TiO_2), (c) to know the effect of the catalytic converter uses Titanium Oxide (TiO_2) on engine performance at 1,000; 1,500; and 2,000. The method used was a quasi-experimental design, which compared experimentally before and after the exhaust gas through a catalytic converter based on TiO_2.

1 INTRODUCTION

Motor vehicles are the means of transportation used to assist human mobility in daily activities. The number of motor vehicles is increasing every year. The Statistic Indonesia (BPS) data shows that the number of motor vehicles in 2013 has reached 104 million units, then in 2014, it has increased to 114 million units, by 2015 the number of motor vehicles reaches more than 121 million units.

Motor vehicles use petroleum fuels as its energy resource. Then the fuel is converted into mechanical energy through the combustion process. From this combustion process, motor vehicles produce harmful pollutants. According to Sugiharto et al. (2016), the total estimated CO pollutant of all activities is about 686,864 tons per year or 48.6 percent of the total emissions of five pollutants. The cause of air pollution is about 80 percent comes from the transport sector, and 20 percent from industry and domestic waste. Whereas, carbon emissions from deforestation and forest degradation are 20 percent.

Pollutant gases that generated by motor vehicles have a harmful impact on human health and the environment. According to research conducted by Hajderi and Bozo (2014) conducted in Albania, motor vehicle exhaust emissions Increase the risk of chronic bronchitis, hormonal hyperactivity, dermatitis, anemia, allergies and tumors in humans and provide an increasing number of cancer patients and liver disease that result in death to 400 casualties. Furthermore, vehicle exhaust gas can also cause acid rain, greenhouse effect, and damage the ozone layer. So the problem of gas dispose of this motor vehicle requires severe handling.

Various studies have been undertaken to reduce the impact and content of emissions, such as with the use of filter material to reduce the pollutant from the exhaust gas emissions of these vehicles. Ceramic materials can be used to absorb HC and CO exhaust emissions. The results of Sinuhaji (2017), which uses ceramics as an absorbent material of CO up to 84.62%, and HC up to 71.64%. So, this acceptable

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ceramic form can be used as a reference in reducing vehicle exhaust pollutants.

Based on the research of Amin and Subri (2016), the manufacture of emission filter material from Ceramic Matrix Composite (CMC) material has been successfully manufactured. Using Titanium Oxide substances as additives are mixed with some other additives, mixing with a rotational speed of 64 rpm for 30 minutes and molded with 25 MPa pressure and 9,500C sintering temperature. The decreasing performance of CO level, up to 99.67% volume at 2,000 rpm engine speed. Thus, based on the description, porous ceramics with additional TiO2 additives may be used to reduce exhaust emissions of motor vehicles.

Based on the description of the problem and the results of previous research, it is necessary to develop the design and use of materials on the catalytic con-verter which is useful, efficient and economical, so that all types of motor vehicles can use catalytic con-verter technology to overcome the problems of envi-ronmental pollution that will be bad for human life.

2 METHOD

This study uses a mixed method, a combination of research and development with experimental research. Research produces to produce the right products in the relevant laboratory and environmental environments. Four D models are used as a model of research and development which consists of 4 stages of development. For valid results, an experimental time series quasi-experimental model was used to determine the use of the designed catalytic converter.

In product development, the catalytic converter design was designed using Autodesk inventor to then be simulated using ANSYS Fluent. The experimental research used: 1) independent variable was a standard exhaust for a light vehicle without catalytic converter and catalytic converter designed with ceramic material with additive Titanium Dioxide (TiO_2), 2) control variables were rotation variation for testing engine performance from 1,000 rpm, 1,500 rpm, and 2,000 rpm, and 3) dependent variables were engine performance (torque and power), exhaust emissions (carbon monoxide, carbon dioxide, and hydrocarbons).

The research design can be described as in the following figure:

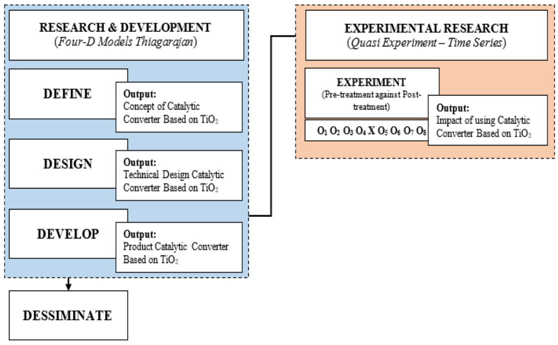

Figure 1: Research design.

Note:
O_1, O_2, O_3, O_4 = testing and measuring exhaust emission before treatment
O_5, O_6, O_7, O_8 = testing and measuring exhaust emission after treatment
X = treatment using a designed catalytic converter

The result of carbon monoxide from the exhaust gas measured using a gas analyzer then incorporated into the test result table as follows

3. DATA ANALYSIS

Data analysis techniques are used to analyze data that has been collected during the experimental process. The data analysis technique used in this research is the comparison of software with the product. The design was observed by simulation

Table 1: The measurement instrument of HC and CO.

Revolution (rpm)	Without Catalytic Converter (%)				With Catalytic Converter (%)			
	O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8
1000 (X_1)	$O_1 . X_1$	$O_2 . X_1$	$O_3 . X_1$	$O_4 . X_1$	$O_5 . X_1$	$O_6 . X_1$	$O_7 . X_1$	$O_8 . X_1$
1500 (X_2)	$O_1 . X_2$	$O_2 . X_2$	$O_3 . X_2$	$O_4 . X_2$	$O_5 . X_2$	$O_6 . X_2$	$O_7 . X_2$	$O_8 . X_2$
2000 (X_3)	$O_1 . X_3$	$O_2 . X_3$	$O_3 . X_3$	$O_4 . X_3$	$O_5 . X_3$	$O_6 . X_3$	$O_7 . X_3$	$O_8 . X_3$

with ANSYS Fluent software, the analysis used was pressure, temperature, and gas flow rate to be tested on the catalytic converter made of ceramic with Titanium Dioxide additive (TiO_2). Ansys software will show the pressure, temperature and flow rate on the inside of the catalytic-based exhaust converter made from ceramic with Titanium Dioxide additive (TiO_2).

The determination of adsorption power of carbon dioxide (CO) through activated carbon adsorbent, the effectiveness of adsorbent is measured by percentage level of adsorbs to exhaust emission and particulate lead. The formula for measuring the effectiveness of adsorbents is as follows:

$$\%\ \mathrm{CO} = \frac{\mathrm{C1} - \mathrm{C2}}{\mathrm{C1}} \mathrm{x} 100\% \quad (1)$$

The determination of HC reduction power by reducing ceramic materials, reducing effectiveness is measured based on percentage reduction rate on HC exhaust emissions. The formula for measuring the effectiveness of adsorbents is as follows:

$$\%\ \mathrm{HC} = \frac{\mathrm{C1} - \mathrm{C2}}{\mathrm{C1}} \mathrm{x} 100\% \quad (2)$$

Note:
C1 is initial emission levels (without treatment)
C2 is gas emission level after treatment with the reduction

The determination of exhaust volume through catalytic converter:

$$\text{Space Velocity} = \frac{\text{Volume flow rate } (V_f)}{\text{Rector volume } (V_r)} \quad (3)$$

where volume flow rate is

$$V_f = \pi . (\frac{Bore}{2})^2 . Stroke\ Length . \left(\frac{N}{2}\right) . 60 \quad (4)$$

and reactor volume, in this case as same as the volume of the catalytic converter through the following equation

$$V_r = \frac{\pi}{4} . D^2 . L \quad (5)$$

4 RESULTS

4.1 Catalytic Converter Design

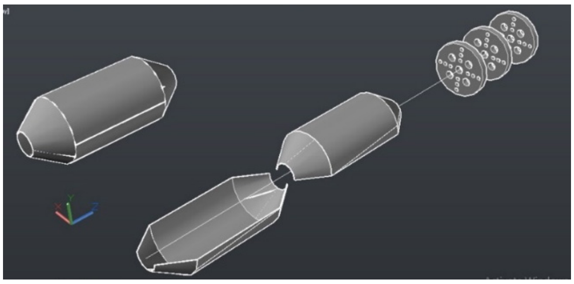

Figure 2: Catalytic converter in assembly.

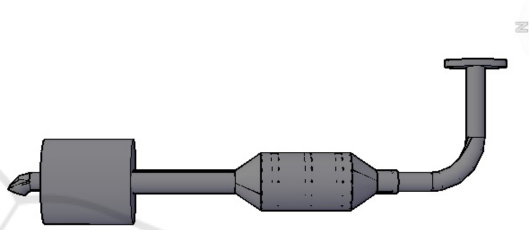

Figure 3: Catalytic converter.

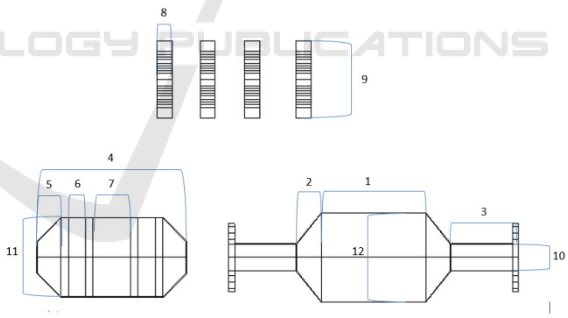

Figure 4: Technical part of the catalytic converter.

4.2 Simulation Result

Figure 5 shows the result of the pressure distribution occurring on the product. The highest value is shown in red which means that it is $5.761x10^2$, while the lowest is $-6.516x10^1$ with blue. As the result of pressure analysis, the unit used is Pascal (Pa). Figure 9 shows the drop in pressure from the pipe header to the muffler tip.

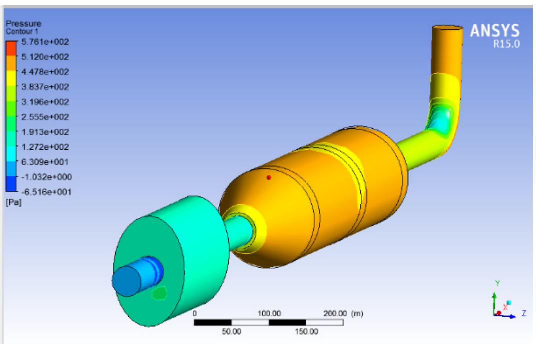

Figure 5: Pressure distribution.

The highest pressure occurs at the bottom radius of the pipe showing a value of $5.761 x 10^2$; this indicates that the part is a critical part because it can cause material damage due to the pressure that occurs during the process of working

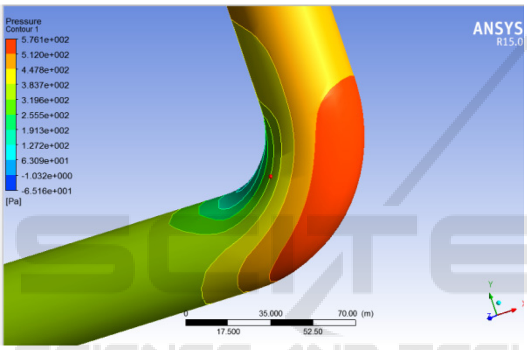

Figure 6: Pressure Distribution on header pipe.

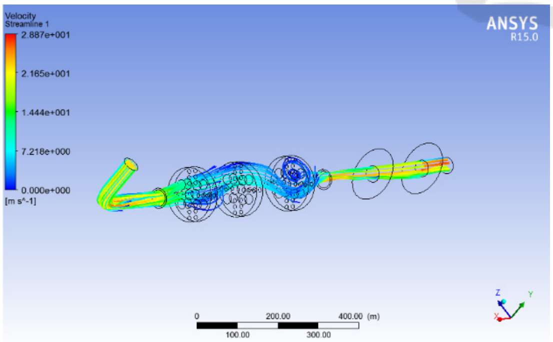

Figure 7: Fluid flow through the catalytic converter.

4.3 Catalytic Converter Design

Based on the results of catalytic converter testing using a ceramic catalyst with titanium dioxide additives to reduce the emission levels of hydrocarbon carbon monoxide gas shown in the following table:

Table 2. The Measurement result of HC and CO

Revolution (rpm)	Exhaust Gases	Without Catalytic Converter	Using Catalytic Converter
1,000	CO	3.768%	3.101%
	CO2	3.28%	4.03%
	HC	111 ppm	140 ppm
	O2	13.81%	13.30%
	Λ	2.052	2.042
1,500	CO	0.586%	0.162%
	CO2	5.40%	5.93%
	HC	41 ppm	29 ppm
	O2	13.25%	12.97%
	Λ	2.467	2.44
2,000	CO	1.193%	1.615%
	CO2	5.21%	5.55%
	HC	89 ppm	46 ppm
	O2	12.87%	12.33%
	Λ	2.276	2.069

To calculate the adsorption power or the decrease of the carbon monoxide and hydrocarbon content of the catalytic converter design can be used the following equation, for CO adsorption power (AB) using:

$$AB_{CO} = \frac{CO_{before} - CO_{after}}{CO_{before}} x100\% \quad (6)$$

for HC adsorption power formula using:

$$AB_{HC} = \frac{HC_{before} - HC_{after}}{HC_{before}} x100\% \quad (7)$$

The results of catalytic converter testing using a ceramic catalyst with titanium dioxide additive at 1000 rpm:
CO before treatment = 3.768 %
CO after treatment = 3.101 %

$$AB_{CO} = \frac{3.768 - 3.101}{3.768} \text{ x } 100\ \%$$

$$= \frac{0.667}{3.768} \text{ x } 100\ \% = 17.70\% \quad (8)$$

The use of the ceramic material as a catalyst material with the addition of titanium dioxide additive at 1,000 rpm can reduce carbon monoxide emission by 17.70% decrease from 3.768% concentration without catalytic converter to 3.101%.
HC before treatment = 111
HC after treatment = 140

$$AB_{HC} = \frac{111 - 140}{111} \text{ x } 100\ \%$$

$$= \frac{-29}{111} \text{ x } 100\ \% = -26.12\ \% \qquad (9)$$

The use of the ceramic material as a catalyst material with the addition of titanium dioxide additive at 1,000 rpm cannot reduce the emission of hydrocarbon gas, but increasing 26.12% of the concentration of 111 ppm without catalytic converter to 140 ppm.

The results of catalytic converter testing using ceramic catalyst with titanium dioxide additive at 1,500 rpm:
CO before treatment = 0.586%
CO after treatment = 0.162%

$$AB_{CO} = \frac{0.586 - 0.162}{0.586} \text{ x } 100\ \%$$

$$= \frac{0.424}{0.586} \text{ x } 100\ \% = 72.35\ \% \qquad (10)$$

The use of ceramic material as catalyst material with the addition of additive at 1,500 rpm can reduce carbon monoxide emission by 72.35% decrease from 0.586% concentration without catalytic converter to 0.162%.
The initial HC content = 41
The final HC content = 29

$$AB_{HC} = \frac{41 - 29}{41} \text{ x } 100\ \%$$

$$= \frac{12}{41} \text{ x } 100\ \% = 29.26\ \% \qquad (11)$$

The use of the ceramic material as catalyst material with the addition of titanium dioxide additive at 1,500 rpm can reduce the hydrocarbon emission by 29.26% from 41 ppm concentration without catalytic converter down to 29 ppm.

The results of catalytic converter testing using a ceramic catalyst with titanium dioxide additive at 2,000 rpm:
The initial CO content = 1.193 %
The final CO content = 1.615%

$$AB_{CO} = \frac{1.193 - 1.615}{1.193} \text{ x } 100\ \%$$

$$= \frac{-0.422}{1.193} \text{ x } 100\ \% = -35.37\ \% \qquad (12)$$

The use of the ceramic material as a catalyst material with the addition of titanium dioxide additive at 2,000 rpm cannot reduce carbon monoxide emissions, but increasing 35.37% of the 1.193% concentration without catalytic converter to 1.615%.
The initial HC content = 89
The final HC content = 46

$$AB_{HC} = \frac{89 - 46}{89} \text{ x } 100\ \%$$

$$= \frac{43}{89} \text{ x } 100\ \% = 50\ \% \qquad (11)$$

The use of the ceramic material as a catalyst material with the addition of titanium dioxide additive at 2,000 rpm can reduce hydrocarbon emissions by 50% from 89 ppm concentration without catalytic converter down to 46 ppm.

Table 3: The result of the exhaust emission test without using a catalytic converter.

Test sequence		1	2	3
Oil temperature	ºC	122	122	122
Revolution	rpm	1,000	1,500	2,000
CO	% vol	3.768	0.586	1.193
CO2	% vol	3.28	5.40	5.21
HC	ppm vol	111	41	89
O2	% vol	13.81	2.467	12.87
Λ	-	2.052	2.467	2.276

Table 4: The result of the exhaust emission test using a catalytic converter.

Test sequence		1	2	3
Oil temperature	ºC	121	122	122
Revolution	rpm	1,000	1,500	2,000
CO	% vol	3.101	0.162	1.615
CO2	% vol	4.03	5.93	5.55
HC	Ppm vol	140	29	46
O2	% vol	13.30	12.97	12.33
Λ	-	2.042	2.445	2.069

5 DISCUSSION

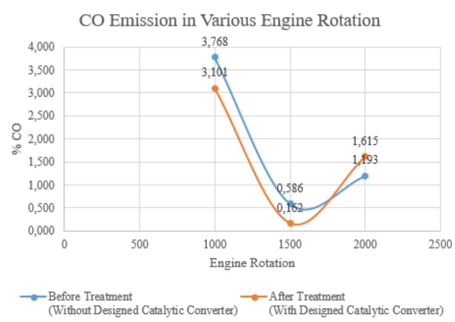

Figure 7: The graph of CO content in emission test with and without a catalytic converter.

The result of gas emission test of a gasoline engine in standard condition without using catalytic converter showed the result of carbon monoxide concentration 3.768% at 1,000 rpm, 0.586% at 1,500 rpm and 1.193% at 2,000 rpm. While, the resulting hydrocarbon is 111 ppm at 1,000 rpm, 41 rpm at 1,500 rpm, and 89 ppm at 2,000 rpm. Then on the exhaust gas emission test using catalytic converter using porous ceramics with titanium dioxide additives showed the results of carbon monoxide concentration of 3.101% at 1,000 rpm, 0.162% at 1,500 rpm, and 1.615% at 2,000 rpm.

The use of a catalytic converter can reduce carbon monoxide as a whole with an average of 18.22%. Test results look very significant at 1,500 rpm engine speed with a decrease of 72.35%. The result is due to the effects of the reaction between titanium dioxide and gasoline exhaust that has a temperature of 700°-1,000°C so that it will heat titanium dioxide up to speed up the reaction. The porous ceramics present in the catalytic converter system are capable of capturing and disentangling the exhaust pollutant of a gasoline engine. The most effective exhaust gas emission reduction is at 1,500 rpm engine speed, this is due to the engine that uses the ideal mixed carbu-rettor with stoichiometry is at medium engine speed.

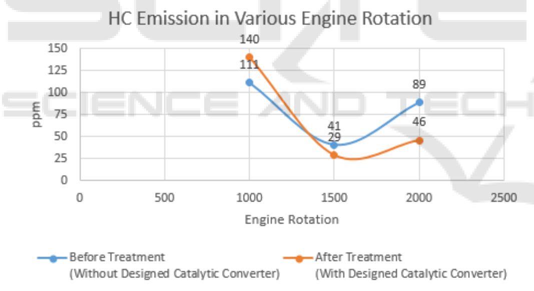

Figure 8: The graph of HC content in emission test with and without a catalytic converter.

The use of a catalytic converter can reduce the overall hydrocarbon level with an average of 17.71%. The most effective reductions occur at 2,000 rpm rotation that is able to reduce the hydrocarbon level by 50%. The result is due to the most optimal burning occurs at a speed of 2,000 rpm. On a gasoline engine using a carburetor, 2,000 rpm is classified within the engine speed with the most optimal fuel consumption.

6 CONCLUSION

The results show that the ability of ceramic catalytic converter with titanium dioxide additive in gasoline engine has an average yield of CO emission reduction with additive titanium dioxide additives 18.22% of a ceramic catalyst. The highest CO emission reduction is in experimental group 2 that is 72, 35% with 1,500 rpm (medium engine speed). The average HC emission reduction with a ceramic catalyst with titanium dioxide additives is 17.71%, and the highest reduction of HC emission is in experimental group 3, i.e., 50% with 2,000 rpm.

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