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The effect of Titanium Dioxide (TiO₂) based metallic catalytic converter on the four-stroke motorcycle engine performance

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Abstract. Many environmentally friendly automotive technologies have been developed to support the blue sky program. Among the several innovations, metallic catalytic converter (MCC) technology used in environmentally friendly motorcycle exhausts system with titanium dioxide (TiO₂) is one of the innovations available to reduce the rise in air pollution due to exhaust emissions. In terms of reducing exhaust emissions, this technology certainly does not doubt its ability. But the problem is that not many researchers have examined the effect of the application of these technologies on engine performance. Thus, the high aim of this study is to analyze the effectiveness of the use of TiO₂ based MCC on the four-stroke motorcycle engine performance. This type of experimental research uses a Yamaha Vixion motorcycle as an object of research. Engine performance testing is performed based on SAE J1349, namely Engine Power Test Code-Spark Ignition and Compression Ignition-Net Power Rating. The equipment used in this study is the inertia of the chassis dynamometer, digital tachometer, digital thermometer, humidity meter, and blower. The independent variables in this study are the standard muffler and modified muffler with TiO₂ based MCC. The control variables are engine speed, engine oil temperature, ambient air temperature and humidity, and Pertamina 101, while the dependent variable is engine performance (torque, power, and fuel consumption). Data analysis techniques using quantitative descriptive methods. This study found that the use of environmentally friendly motorcycle mufflers with TiO₂ based MCC technology could increase the torque of the Yamaha Vixion motorcycles. In line with these results, vehicle power also increases, and fuel consumption is relatively economical if the TiO₂-based MCC is compared to standard exhaust.

1. Introduction

The 13th global goal of the seventeen sustainable development goals (SDGs) that has been declared by the United Nations from 2016-2030 is to take concrete actions to address climate change and its impacts [1-3]. Activities that must be carried out are making strategic efforts to reduce air pollution, especially exhaust gas emission that are generated from motor vehicle exhaust fumes. Therefore, a smart solution is needed to control the exhaust emissions of these motorized vehicles. One technology that can be applied is a catalytic converter that is mounted on a motorized vehicle exhaust. Considering that 65-85% of exhaust emissions are emitted by motor vehicle exhaust fumes [4], the application of catalytic converter technology in motorized vehicles is an absolute must.

Unfortunately, catalytic converter technology is still considered quite expensive so far, so the use of this technology in motorbikes is even less widespread. The high cost of the catalytic converter is because



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of the materials made from precious metals (Nobel metals), such as Platinum (Pt), Palladium (Pd), and Rhodium (Rh) and the level of availability in the market is small. Still, it can reduce exhaust emissions between 98-99% [5]. Therefore, recently many researchers from universities and research and development institutions have started to develop catalytic converters derived from transition metals.

Based on research conducted by Kalam et al. (2009) using titanium dioxide (TiO_2) and cobalt oxide (CoO), it was concluded that there was a reduction in NO_x , CO, and HC emissions by 90%, 89%, and 82% respectively in vehicles fueled with CNG (compressed natural gas) [6]. Further research conducted by Abdullah (2012) using TiO_2 and FeO materials was carried out on gasoline-fueled cars resulting in a decrease in CO emissions of 2.67% -42.2% and HC by 1.95% -27.61% [7]. Meanwhile, further research conducted by Wicaksono & Warju (2015) using TiO_2 coated wire mesh stainless steel was able to reduce CO and HC emissions by an average of 20.96% and 23.26% on 4-stroke motorbikes [8].

Referring to previous research, we know that titanium dioxide catalytic converters have the undoubted ability. Khoiron et al. (2018) proved that titanium dioxide catalytic converters were able to reduce CO emissions by 35% and HC by 50% [9]. This of course has a good impact on improving air quality in the environment. But unfortunately, catalytic converters that are used continuously will quickly decrease the activity of the material. Generally, the cause of the decreased reactivity is due to several things such as the buildup of lead in the wall of catalytic converters due to using wrong fuel. Besides, it is also caused by the melting of the metal catalyst due to the high operating temperature for an extended period [10]. Thus, the performance of a four-stroke motorcycle engine will also continue to decline.

In terms of reducing exhaust emissions, of course, the metallic catalytic converter (MCC) titanium dioxide (TiO_2) technology does not need to be doubted. However, the problem is that not many researchers have examined how the application of this technology affects engine performance. Thus, the significant objective of this study is to analyze the effectiveness of using MCC TiO_2 on the performance of a four-stroke motorcycle.

2. Research Method

2.1. Experimental exhaust system design

The design of the metallic catalytic converter casing in the experimental exhaust system refers to the design made by A. Graham Bell [11]. In this design, the pipe diameter before and after the catalyst is made taper, where for the inlet pipe, the entry taper is 10° , and the outlet pipe, exit taper is 15° , as shown in Figure 1.

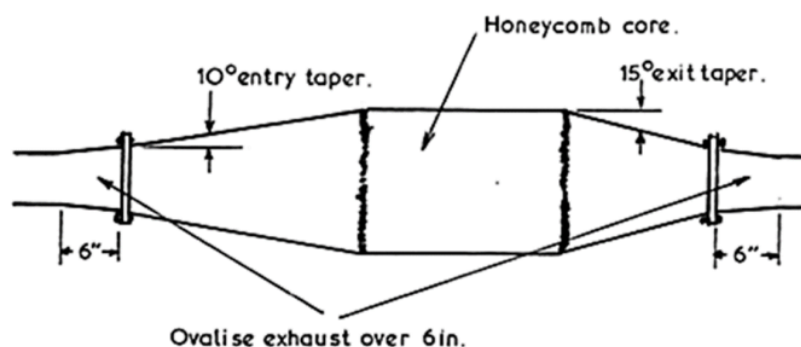


Figure 1. Modification of the MCC TiO_2 casing

2.2. Design of TiO_2 in the exhaust experimental MCC

The method of making active metal catalysts is a copper (Cu) plate coated with TiO_2 arranged in a cylindrical casing. To get the maximum surface area, the copper plates are arranged in folds with a groove height ranging from 2 mm, 3 mm, and 4 mm [12]. The metallic catalytic converter casing contains a copper plate coated with titanium dioxide (TiO_2) with a catalyst length of 100 mm and a

diameter of 65 mm with a curve height of 2 mm, 3 mm, and 4 mm. The design of the MCC shape made from a Cu plate can be seen in Figure 2.

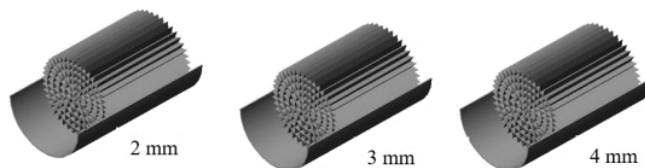


Figure 2. MCC made from copper plate

The MCC casing was then mounted on the experimental exhaust. The experimental exhaust design was designed to reduce noise levels. Therefore two bulkheads were installed after the MCC. The parts and dimensions of the 2013 Yamaha Vixion Lightning experimental exhaust are shown in Figure 3.

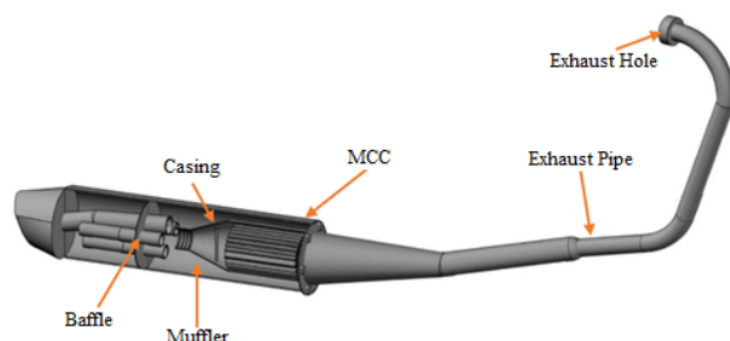


Figure 3. The Yamaha Vixion Lightning experimental exhaust system parts

2.3. 3 Types, objects, standards, instruments, and research data analysis techniques

This type of research is experimental research. The research object was a Yamaha Vixion motorcycle in 2013. The engine performance testing standard is based on SAE J1349 [13]. The independent variables in this study were standard exhaust and MCC TiO_2 experimental exhaust. Control variables are engine speed, engine oil temperature, ambient air temperature and humidity, and Pertamina fuel. At the same time, the dependent variable is engine performance (torque, and engine power). The data analysis technique used a quantitative descriptive method [14]. Mechanical Performance Testing, Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Surabaya. In full, the research tools and instruments that will be used are as shown in Figure 4.



Figure 4. Schematic of the research instrument

3. Results and Discussion

3.1. Engine torque

The use of a titanium dioxide catalytic converter can affect changes in torque. A standard exhaust that has been modified with a titanium dioxide catalytic converter will affect the change in torque produced by the engine. To find out the difference in torque, it can be seen in Figure 5.

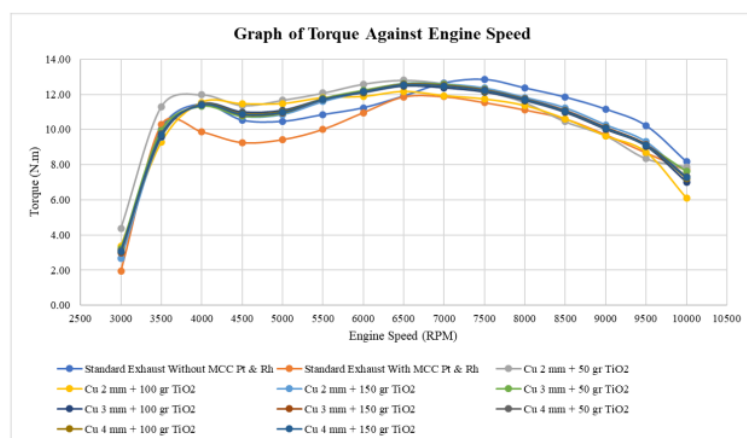


Figure 5. Graph of torque against engine speed

In Figure 5 above, in general it can be seen that by using a standard exhaust with MCC Pt & Rh, Cu 2 mm + 50 gr TiO₂, Cu 2 mm + 100 gr TiO₂, Cu 2 mm + 150 gr TiO₂, Cu 3 mm + 50 gr TiO₂, Cu 3 mm + 100 gr TiO₂, Cu 3 mm + 150 gr TiO₂, Cu 4 mm + 50 gr TiO₂, Cu 4 mm + 100 gr TiO₂, and Cu 4 mm + 150 gr TiO₂ can increase torque when compared to exhaust standard without MCC Pt & Rh. This is because the design of the catalytic converter housing refers to a design that has been researched by A. Graham Bell, by optimizing the exhaust gas flow through a modified taper inlet catalytic converter housing with an angle of 10° and a taper outlet with an angle of 15°. The design drawings of the catalytic converter housing exhaust experiment with Cu coated titanium dioxide can be seen in Figure 6 [15,16].

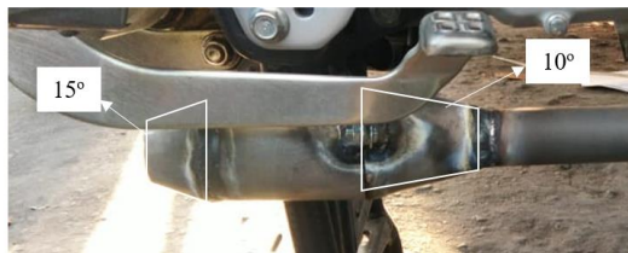


Figure 6. Inlet and outlet design of TiO₂ coated Cu at experimental exhaust pipe

In variations of Cu 2, Cu 3, Cu 4 mm coated with 50 gr TiO₂, the average changes in torque increase of 14.58%, 10.94%, and 10.61% compared to the torque using a standard exhaust with MCC Pt & Rh. In variations of Cu 2, Cu 3, Cu 4 mm coated with 100 gr TiO₂, the average changes in torque increase of 10.32%, 10.32%, and 10.49% compared to the torque using a standard exhaust with MCC Pt & Rh. In the titanium dioxide catalytic converter variations of Cu 2, Cu 3, Cu 4 mm coated with 150 gr TiO₂, the average change in torque increase is 10.26%, 10.55%, and 10.55% when compared to torque using a standard exhaust with MCC pt & Rh. Thus, when compared with variations of Cu 2, Cu 3, Cu 4 mm coated with 50 gr TiO₂ and 100 gr TiO₂, the backpressure of variations Cu 2, Cu 3, Cu 4 mm coated with 150 gr TiO₂ tends to be higher. This higher backpressure was due to the higher amount of catalyst coated in the variation of Cu 2, Cu 3, Cu 4 mm, namely 150 grams. So that the exhaust gas passage on the surface of the copper plate is getting tighter, this tightening of the exhaust gas passes blocks the flow of exhaust gases through the catalytic converter [17,18]. The implementation of a three-way design in the catalytic converter also has an essential effect in reducing exhaust emissions [19,20]. The use of the right design and materials has the potential to reduce CO emissions in the range of 98% and CO emissions in the range of 95% [21,22].

3.2. Engine power

The use of a titanium dioxide catalytic converter can affect power changes. A standard exhaust that has been modified with a titanium dioxide catalytic converter will affect the power generated by the engine. To find out the change in power can be seen in Figure 7.

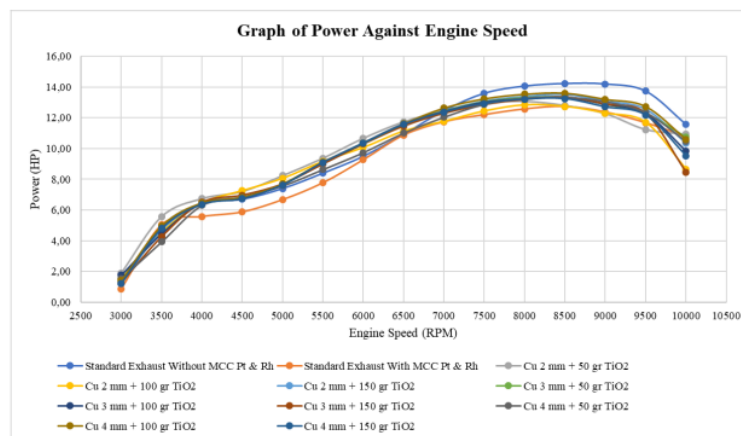


Figure 7. Graph of power against engine speed

In Figure 7 above generally it can be seen that using a standard muffler without MCC Pt & Rh, Cu 2 mm + 50 gr TiO₂, Cu 2 mm + 100 gr TiO₂, Cu 2 mm + 150 gr TiO₂, Cu 3 mm + 50 gr TiO₂, Cu 3 mm + 100 gr TiO₂, Cu 3 mm + 150 gr TiO₂, Cu 4 mm + 50 gr TiO₂, Cu 4 mm + 100 gr TiO₂, and Cu 4 mm

+ 150 gr TiO₂ can increase power when compared to standard exhaust with MCC Pt & Rh. This is because the torque data has also increased. If the torque increases, the power will also increase, because the formula for getting power (PS) must be known first the torque value. In the titanium dioxide catalytic converter with variations of Cu 2, Cu 3, Cu 4 mm coated with 50 gr TiO₂, the average percentage change in the resulting increase in power was 14.46%, 10.90%, and 9.63% when compared to standard exhaust power with MCC Pt & Rh.

In variations of Cu 2, Cu 3, Cu 4 mm coated with 100 gr TiO₂, the average percentage change in the increase in the resulting power is 10.35%, 11.66%, and 11.87% when compared to the standard exhaust power with MCC Pt & Rh. In the variation of Cu 2, Cu 3, Cu 4 mm coated with 150 gr TiO₂, the average percentage change in the resulting increase in power is 10.37%, 10.21%, and 9.61% when compared with standard exhaust power with MCC Pt & Rh. So it can be stated that with an increase in torque, it will also be followed by the rise in power [23]. The back pressure influences this increase in torque and power in the exhaust. The higher the backpressure, the lower the torque and power produced. This is consistent with the results of research by Bhure [24], which states that the higher the backpressure, the lower the engine power. Meanwhile, Sapra et al. [25] revealed that high back pressure could reduce engine operating limits, increase fuel consumption, and cause exhaust fumes. Strengthening this statement, B. et al. [26] stated that the modification of the appropriate exhaust design has the potential to reduce the backpressure effect.

4. Conclusion

Based on the results of testing and discussion of research that has been conducted, it is known that the use of environmentally friendly motorcycle exhaust with MCC TiO₂ technology can increase the torque and power of Yamaha Vixion Lightning motorbikes in 2013. The best changes in increasing torque and power are in MCC TiO₂ variations Cu 2, Cu 3, Cu 4 mm coated with 50 gr TiO₂. The changes in the best increase in torque are respectively 14.58%, 10.94%, and 10.61% compared to the standard exhaust torque with MCC Pt & Rh. Whereas, the changes in the best power increase, respectively 14.46%, 10.90%, and 9.63% compared with the standard exhaust power with MCC Pt & Rh.

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