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Evaluating the Impact of Alternative Material-Based Catalytic Converters on Automotive Exhaust Emissions

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Abstract

Pollution air in cities in Indonesia, such as Jakarta, Tangerang, and Bandung, is mainly caused by exhaust emissions from vehicle motorized like carbon monoxide (CO) and hydrocarbons (HC), which originate from burning material burn the ones that are not perfect. Technological catalytic converters are used to reduce emissions, but converters made from metal have their own cost. This study evaluates exhaust Metallic Catalytic Converter (MCC) technology with alternative materials copper (Cu). The result shows that the MCC Cu exhaust system is significantly more effective in reducing CO and HC emissions than exhaust without the original equipment manufacturer (OEM) catalyst and exhaust. The average CO emissions are 2.13 %Vol, and HC emissions are 198 ppmVol, lower than the second exhaust type. Findings This shows that MCC Cu exhaust is more effective in reducing danger and is more economical than catalytic converters made from a noble metal, offering a sustainable and affordable solution for vehicle air pollution.a

Keywords: *Pollution air, catalytic converters, exhaust emissions, alternative materials*

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INTRODUCTION

In Indonesia, the level of pollution air in the atmosphere has reached alarming levels. According to the report IQAir [1] on June 4, 2024, South Tangerang and Jakarta are included in the category city with quality air that isn't healthy, while Bandung, Pekanbaru, Palembang, Bogor, and Jambi are included in the category quality air currently. Many factors influence the enhancement of this air pollution, one of them being the high exhaust emissions produced by motorized vehicles, especially in urban areas. Exhaust gas emissions usually occur due to incomplete combustion. When burning does not perfectly happen, exhaust vehicles emit more Lots particles such as CO, HC, NOx, SOx, and soot [2].

The organization (WHO) has stated that polluted air is one of the risk environments to health, and more than 80% of the population is the most vulnerable [3]. Pollution in the air is closely related to diseases that are not infectious, including cardiovascular disease, chronic respiratory disease, and lung cancer. In Jakarta, disease No infectious accounted for 79% (36,000 deaths) of total deaths in 2019 [4]. Apart from that, air pollution caused by vehicle emissions is not only considered a pollutant dangerous for the health of humans but also impacts negatively on creature life other [5]. According to data released by Korlantas Polri in February 2024 [6], the population of various types of motorized vehicles in all regions of Indonesia, to be precise in 34 provinces, totaling 162,580,217 units. With so, If the automotive sector donates around half of the total global emissions, it gives rise to a threat significant environment.

There are two ways to do this to control emissions. First, the modification method is burning [2]. Superiority: this method can increase the efficiency of material burns and reduce exhaust gas emissions produced directly from the combustion process. However, there are drawbacks, such as the cost of high implementation and the need to change significant impact on the design and technology of existing engines [7]. Second, exhaust gas processing. Compared to the first method, this method is easier implemented on existing vehicles, and there is no need to remodel the design engine [8]. Superior, this method is his ability to reduce exhaust gas emissions after combustion. However, there are drawbacks, such as the need for routine maintenance and the inability to overcome problems efficiently, such as material burns directly. Therefore, at this moment, many scientists are focusing on using technology like catalytic converters because of the advantages that can be applied to vehicles without changing construction engines.

Several previous studies naturally support the successful use of catalytic converters. Warju et al. [9] studied the effectiveness of brass-based catalytic converters for reducing exhaust gas emissions from motorcycle four-stroke. The results show that the CO and HC emissions subtraction was significant, averaging 52% and 29% for each round engine. Furthermore, Tan et al. [10] researches the influence of structural parameters on performance catalytic dual-carrier converters for heavy-duty natural gas engines. Findings from Fuzzy Gray Relational Analysis (FGRA) show that factors that influence the efficiency of CH4 and NO conversions are the diameter and length of the catalyst. Case 7 shows performance conversion best with enhancement efficiency CH4 and NO conversions were 14% and 19.9% compared with case 2. Farinango-Herrera et al. [11] conducted a study to analyze exhaust gas emissions of multi-point fuel injection (MPFI) with manipulated injection parameters. The result shows a combination of certain things that reduce its emission without reducing the efficiency and performance of the engine.

The previous study shows that using a catalytic converter is very efficient and can potentially develop more carry-on. On vehicles, automotive manufacturers have completed it with a technology catalytic converter. However, the challenges are material from the catalytic original equipment manufacturer (OEM) made converter from metal glorious. Metal's glorious price material has high raw value on the market, though its abilities lower CO and HC emissions by up to 98%. Therefore, the study aims to evaluate the ability of exhaust Metallic Catalytic Converter (MCC) technology by using alternative materials, copper (Cu), to lower CO and HC emissions if compared to exhaust without OEM catalyst and exhaust.

RESEARCH METHOD

Experimental setup

Experiment carried out in the Laboratory Engine Performance Testing, Department of Mechanical Engineering, Universitas Negeri Surabaya. Appearance schematic from testing exhaust gas emissions in a way experimental shown in Figure 1.

The object of this research is the SI engine, specifically the Yamaha Vixion Lightning. The testing range of 1,500 to 9,000 rpm spans from idle to the vehicle's operational limit. This range is determined by field testing practices [12], engine mechanical limits, and the need to assess performance at both low (e.g., 1,500 rpm for idle) [13] and high speeds, ensuring compliance with relevant standards [14]. After treatment, the engine was tested using MCC Cu technology. For clarity, the detailed specifications of the engine and testing tools are summarized in the Table 1.

Metallic Catalytic Converter

Metallic Catalytic Converter Copper (MCC Cu) is an after-treatment technology designed to reduce the levels of pollutants produced from the combustion process and exit through the exhaust tip. These pollutants mainly appear when the engine operates in lean mixture conditions, usually around 250–400°C [15], [16]. For more details, MCC Cu technology can be seen in Figure 2.

Experimental procedure

In this study, an MCC Cu was installed on the exhaust system of a Yamaha Vixion Lightning engine to evaluate its effectiveness in reducing emissions. Testing was conducted at an engine speed range of 1,500 rpm (idle) to 9,000 rpm with load, with emis-

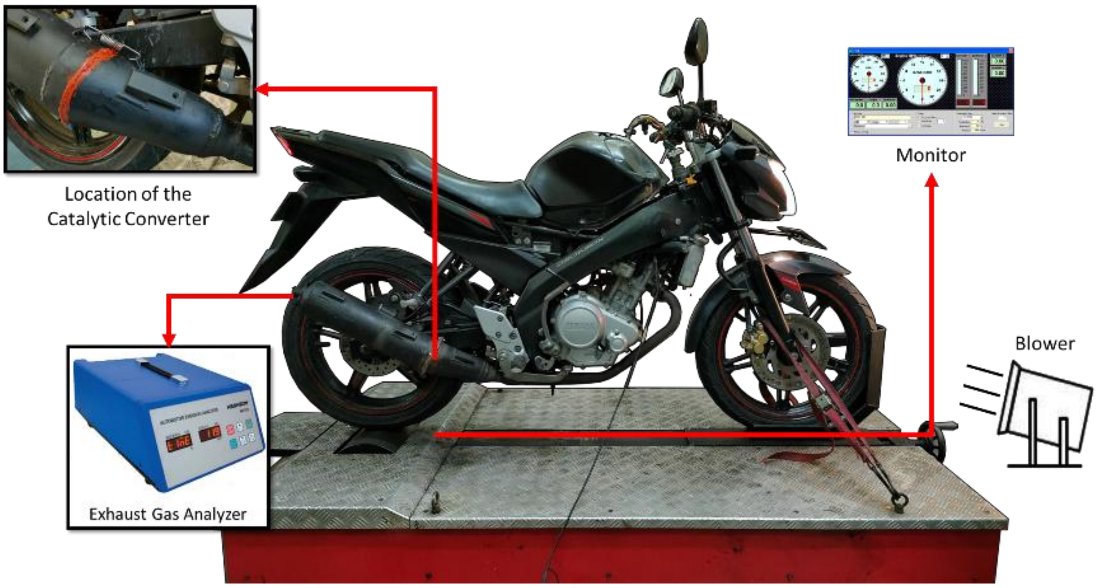

Figure 1. Schematic view of the experimental set-up.

Table 1. Technical Specifications of the Engine and Testing Equipment

Category	Parameter	Specification
Engine	Type	SI Engine
	Model	Yamaha Vixion Lightning
	Testing RPM Range	1,500 - 9,000 rpm
Dynamometer	Model	Rextor Pro-Dyno Chassis
	Voltage	220 V, 50/60 Hz
Emission Testing Tool	Tool Name	Heshbon HG-520
	Voltage	220/240 V, 50/60 Hz
	Measurement Range	0-9.99%
	Resolution	0.01%

Figure 2. MCC Cu Technology

sion data recorded every 1,000 rpm interval. Emission parameters such as Lambda (λ), Air Fuel Ratio (AFR), CO, HC, CO_2, and O_2 were measured before and after the installation of the MCC Cu. The test was repeated three times under the same operating conditions, and the average value was used for evaluation. Emission measurements followed the SNI 09-7118.3-2005 standard [17] to ensure data reliability. This method minimizes engine performance variations and measurement errors, resulting in accurate conclusions about exhaust emission reduction.

RESULTS AND DISCUSSIONS

Trends testing the exhaust gas emissions of the Yamaha Vixion Lightning engine can be seen in Figure 1. From the picture, you can know what the combustion process is. Every sample or every Revolution per Minute (rpm) has happened in a way perfect or No. In terms of this, an indicator that can be referenced is the AFR. AFR is the ratio between mass air and materials burn that comes into room burning. The ideal ratio for perfect combustion is 14.7:1 (14.7 kg air and 1 kg material burn). A higher AFR value of 14.7 shows that a mixture of air and materials contains too much air, which is called a "lean mixture" [18]. On the other hand, the AFR value is smaller, 14.7, showing that the mixture of air and materials contains more Lots material burn, called a "rich mixture" [19].

Referring to Figure 2, "WCC" is an abbreviation for exhaust "without catalytic converter". “OEM” is an abbreviation for equipped exhaust with an "original equipment manufacturer" catalytic converter. Meanwhile, "MCC Cu" is an abbreviation for the equi-

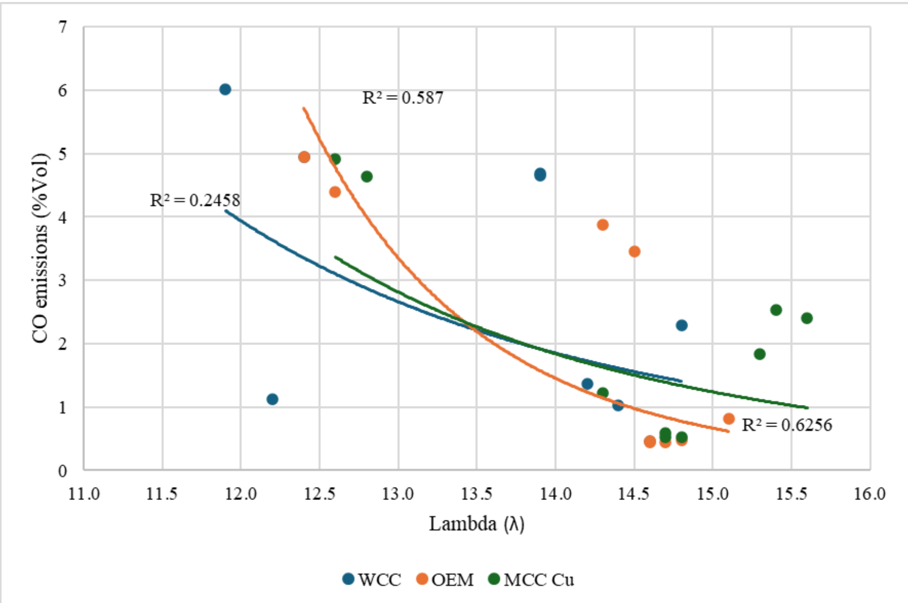

Figure 3. Trend of CO versus lambda (λ)

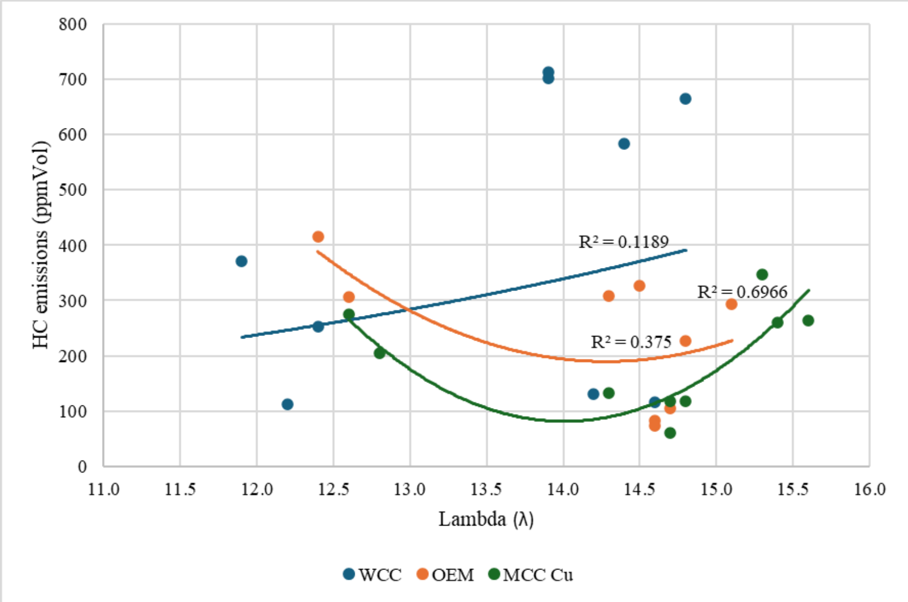

Figure 4. Trend of HC versus lambda (λ)

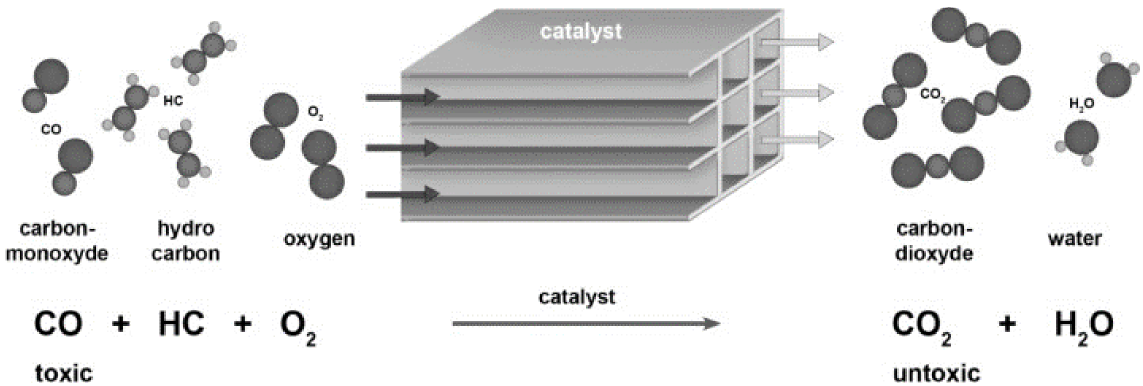

Figure 5. Oxidation and Reduction Processes on Surfaces Catalytic Converter [25]

pped exhaust with "metallic catalytic converter copper. " In terms of this, Fig. 3 average shows the CO emissions produced by each exhaust. Temporary, that's standard deviation, which shows how much of a big variation or deviation of CO emissions is from the average on each variation.

Based on the average CO emissions (Figure 3), the WCC exhaust shows the highest mark of 2.95 % Vol. This indicates that without a catalyst, CO emissions produced by vehicles tend to be taller than those produced by other types of exhaust. Dey & Mehta's Research [20] supports these findings by mentioning that vehicles not equipped with catalytic converters produce high CO emissions because an oxidation process addition converts CO to CO2 (Figure 5). In contrast, OEM and MCC Cu exhausts show more CO emissions on average low, namely 2.14 %Vol and 2.13%Vol respectively. Findings are consistent with the study by Warju et al. [21], which shows the use of catalytic converters. Both OEM and alternative used materials reduce CO emissions.

In terms of variation in CO emissions, standard data deviation gives findings more carry-on. WCC exhaust has a standard deviation of 2.10, indicating a variation of sufficient CO emissions. According to theory statistics from Montgomery & Runger [22], a standard deviation low shows that more data concentrated around an average value signifies stability and consistency in the performance system. In contrast, OEM and MCC Cu exhausts have low standard deviations, specifically 1.96 and 1.68, respectively. This shows that CO emissions in the configuration that uses a catalytic converter are more consistent and stable than WCC. Findings The study of Dey & Dhal supports this [17], which states that catalytic converters help guard the stability of the CO oxidation process, producing more consistent emissions.

Apart from CO, the average HC emissions also show a significant difference. WCC exhaust has the mark 405 ppmVol, indicating that without a catalytic converter, the level of HC emissions produced tends to be higher. This finding is in line with a study by Ariyanto et al. [18], which shows that vehicles without catalytic converters tend to produce more HC emissions because there is no effective mechanism to oxidize unburned HC in the combustion chamber. Research by Kritsanaviparkporn et al. [24] discloses that catalytics are very effective converters in reducing HC emissions because their abilities facilitate chemical reactions that convert HC to CO_2 and H_2O (Figure 5).

Regarding the average HC emissions shown in Figure 4, type WCC exhaust has the highest mark, namely 405 ppmVol. This indicated that the emission level of hydrocarbons produced was higher without a catalytic converter. A study by Ariyanto et al. [23] shows that vehicles without catalytic converters tend to have more HC emissions because no existing mechanism effectively oxidises hydrocarbons that are not burnt in the engine. In contrast, OEM and MCC Cu configurations show lower average HC emissions, 238 ppmVol and 198 ppmVol. Research by Kritsanaviparkporn et al. [24] discloses that catalytic converters are very effective in reducing the emission of hydrocarbons because their abilities facilitate chemical reactions that convert HC into CO_2 and H_2O (Figure 5).

Standard deviation also provides information about variations in HC emissions. WCC exhaust has a standard deviation of 263, showing enough variety in HC emissions. This means HC emissions in the WCC exhaust are taller and less consistent. This is supported by Robles-Lorite et al. [16], who state that without a catalytic converter, fluctuation in the combustion process causes variation in emissions. On the other hand, OEM and MCC Cu exhausts have a low standard deviation, namely 123 and 95, showing that HC emissions on types of exhaust that use catalytic converters are more stable and consistent. Milku et al. [21] also found that catalytic converters lower average HC emissions and increase emission consistency thanks to more controlled oxidation processes.

Average CO_2 emissions, as shown in Figure 6, for exhaust WCC, are 10.88 %Vol, the lowest value among third-type exhaust. This shows that without a catalytic converter, the

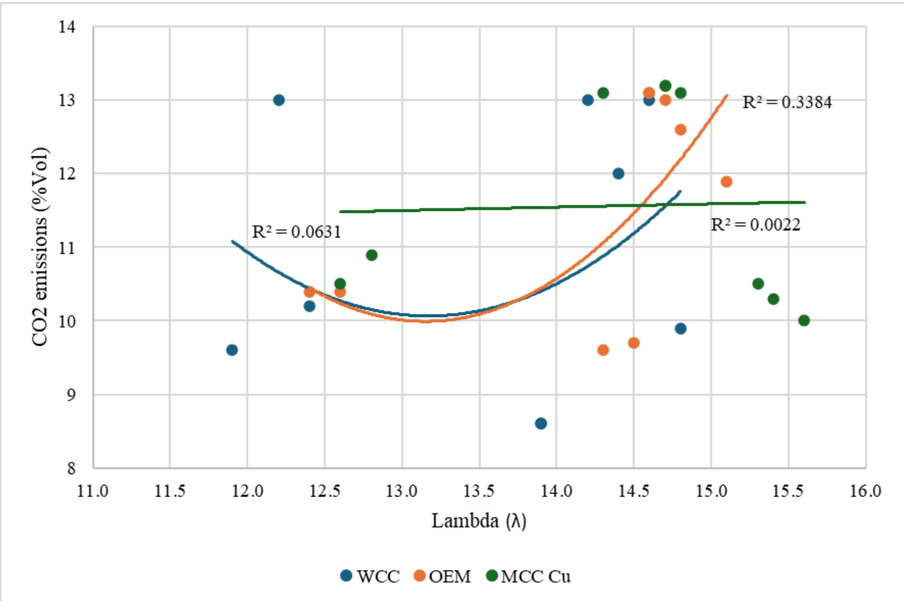

Figure 6. Trend of CO_2 versus lambda (λ)

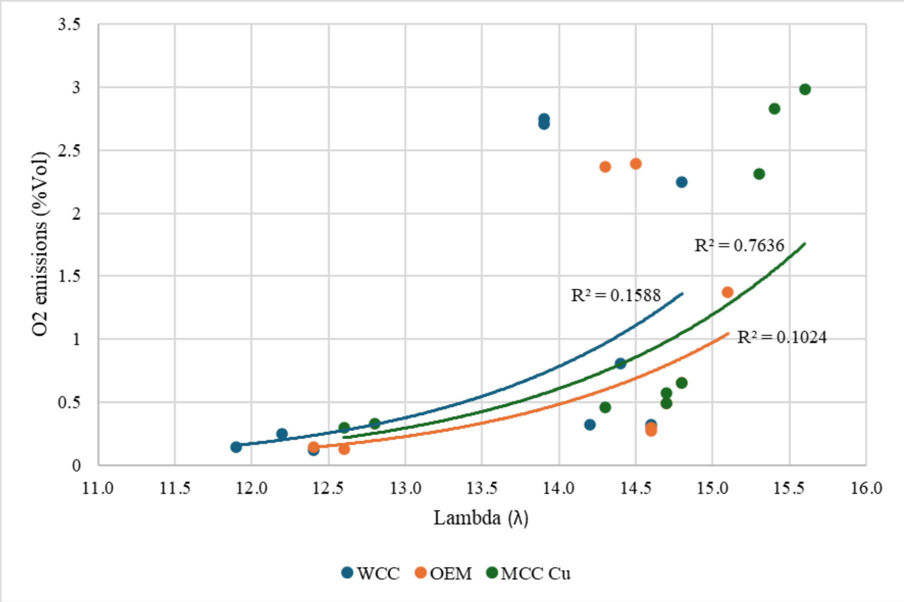

Figure 7. Trend of O_2 versus lambda (λ)

CO_2 emissions produced tend to be lower. In contrast, OEM and MCC Cu exhausts show lower CO_2 emissions on average, namely 11.53 %Vol and 11.64 %Vol, respectively. Although the difference is insignificant, this shows that using a catalytic converter can increase CO_2 emissions compared to WCC exhaust. According to a study by Garba et al. [27], catalytic converters can slightly increase CO emissions due to additional oxidation processes occurring in the catalyst.

Next, the standard deviation gives information about the variation in CO_2 emissions in each type of exhaust. WCC exhaust gain marks a standard deviation of 1.88, which shows enough variety in CO_2 emissions. This means that CO_2 emissions in the WCC exhaust are less consistent. In contrast, OEM and MCC Cu exhausts have a standard deviation, namely 1.50 and 1.45, respectively, indicating that CO_2 emissions in the exhaust using catalytic converters are more stable and consistent. Consistency This is supported by research by Mei et al. [23], who found that the enhancement of CO_2 emissions is in line with a decline in CO and HC emissions caused by more efficient oxidation processes.

The average O_2 emissions, as shown in Figure 7, for exhaust WCC is 1.07 %Vol, showing relative O_2 levels tall compared to other exhausts. This finding is consistent with research by Farinango-Herrera et al. [11], who mentioned that exhaust without a catalyst tends to show variation in emissions Because of his incompetence in controlling the oxidation and reduction processes of exhaust gases effectively. In contrast, the OEM and MCC Cu configurations have low average O_2 emissions, namely 0.90 %Vol and 1.21 %Vol, respectively. Difference This shows that converter catalytic can influence O_2 levels in the flue gas, with MCC Cu generating higher O_2 levels than OEM. A study by Zhang et al. [24] also supports the idea that using a catalytic converter can increase the efficiency of oxidation of CO and HC to CO_2 and H_2O, which in turn directly influences remaining O2 levels in the exhaust gas.

Standard deviation O_2 emissions provide additional information about the variation in each configuration. For WCC, the standard deviation is 1.15, which shows enough variety in O_2 levels, indicating that O_2 emissions in the configuration without converter catalytic are inconsistent enough. In contrast, OEM and MCC Cu configurations have low standard deviations, namely 0.92 and 1.14, respectively. This shows that O_2 levels in the configuration with converter catalytic are more stable and consistent. The study by Zhang et al. [24] also showed that the stability of O_2 emissions is important for performance converter catalytic in maintaining effective control of reaction chemistry in system gas exhaust.

CONCLUSIONS

Based on the results of data research and discussion related to the type of WCC, OEM, and MCC Cu exhausts, it can be known that the MCC Cu exhaust system is significantly more effective in reducing CO and HC emissions. MCC Cu exhaust shows performance best in reducing CO and HC emissions compared with OEM and WCC exhausts. Average CO emissions for MCC Cu exhaust were noted at 2.13 %Vol, the lowest compared to OEM exhaust (2.14 %Vol) and WCC (2.95 %Vol). Regarding HC emissions, MCC Cu exhaust also shows results best with an average of 198 ppmVol, much lower compared to OEM exhaust, which has an average of 238 ppmVol, and WCC, which has an average of 405 ppmVol.

This result confirms that MCC Cu exhaust effectively lowers CO and HC emissions and offers more performance consistency. The standard deviation For CO and HC emissions in the MCC Cu exhaust, 1.68 and 95, respectively, also show more variety than OEM and WCC exhausts. In other words, MCC Cu exhaust delivers more performance stability and consistently reduces emission dangers, making it a better choice than the type of exhaust tested in the study.

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DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article for our colleagues

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