# Analyzing Transition Metallic Catalytic Converter Impact on Four-Stroke Motorcycle Fuel Consumption

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ABSTRACT

Increased exhaust emissions from motor vehicles have become a major concern in efforts to reduce air pollution. One developed solution is the use of transition metallic catalytic converter (TMCC) technology in vehicle exhaust systems. This study aims to compare the fuel consumption efficiency of three types of exhaust systems, namely standard exhaust without a catalyst (STD WC), the standard exhaust with Original Equipment Manufacturer catalyst (STD OEM), and an exhaust system equipped with a Copper-Coated Chrome Metallic Catalytic Converter (TMCC CuCr). The data analysis method employed a quantitative approach by collecting fuel consumption data at each rpm and analyzing the mean and standard deviation. The research findings indicate that STD OEM has a lower average fuel consumption (0.80 liters per hour) and smaller standard deviation (0.06) compared to TMCC CuCr (0.83 liters per hour and 0.07). Although TMCC CuCr demonstrates good efficiency, STD OEM remains the best choice in terms of fuel efficiency. However, if the differences in fuel consumption and standard deviation are considered insignificant, TMCC CuCr could be a more economical alternative with its affordable price and greater material availability. Furthermore, its fuel consumption performance is not significantly different from that of STD OEM.



***Keywords:*** *Air pollution, exhaust emissions, fuel consumption, motor vehicles, transition metallic catalytic converter*

## I. Introduction

The exhaust emissions from motor vehicles worldwide are a major contributor to the increasing levels of air pollution. Recognizing this factor, various efforts have been made to minimize air emissions from engines, including the implementation of two regulations issued by the Ministry of Environment (MOE). These regulations are Minister of Environment Regulation No. 5/2006 Regarding the Emission Standards for Old Motor Vehicles [1] and Minister of State for Environment Regulation No. 4/2009 Regarding the Emission Standards for New Type Motor Vehicles [2] for category L vehicles. Category L motor vehicles are the latest type of 2 (two) or 3 (three)-wheeled motor vehicles with internal combustion engine propulsion and spark-ignition engine propulsion (2-stroke or 4-stroke) in accordance with SNI 09-1825-2002.

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In general, emissions exiting the tailpipe include three harmful gases: carbon monoxide (CO), nitrogen oxides (NOx), and hydrocarbons (HC) that need to be addressed. In this regard, transition metallic catalytic converter (TMCC) technology is an alternative solution to be applied to the exhaust system of both cars and motorcycles. This is corroborated by earlier studies, such as those by Udhayakumar et al. [3], who looked into zinc catalytic converters with a vanadium coating. According to the findings, CO emissions were reduced by 60% and NOx emissions by 70%. Additionally, copper oxide nanoparticle-based catalytic converters were tested by Prabhahar et al. [4], who found that at 250°C, CO emissions were reduced by 50% and at 300°C, HC emissions were reduced by 50%. In line with the findings of previous research, Ariyanto et al. [5] also proved that CO emissions were reduced by 24%, and HC emissions were reduced by 30% after using a catalytic converter made from copper-coated chrome catalytic converter on a motorcycle exhaust.

Regarding its capabilities, there is no question that using TMCC is quite effective in lowering CO and HC emissions that are released through the exhaust pipe. However, there are still issues with TMCC utilization, notably in relation to how it affects fuel consumption. Several studies related to the use of TMCC on fuel consumption have also been conducted. Warju et al. [6] found that the use of metal catalytic converters in four-stroke engines did not significantly reduce fuel consumption. In fact, it resulted in an increase of 87%. This was due to an increase in back pressure caused by the steeper outlet angle of the casing. Another study conducted by Ellyanie & Oktabri [7] demonstrated that the use of copper catalytic converters in mufflers reduced fuel consumption, with a significant decrease of 12.56% at a Prony load of 0.9 kg and an average reduction of approximately 8.84%. Meanwhile, through his research, Zaloznov [8] successfully determined the average fuel consumption when the engine used a catalytic converter in idle conditions and its value under real testing conditions.

This research is now investigating the effectiveness of TMCC in relation to fuel consumption in an effort to allay these worries. As a result, the phenomena that appear in relation to fuel consumption following the usage of TMCC can be explained. Additionally, the fundamental component of the TMCC under examination is mostly made of layered copper-chromium (CuCr) materials.

## II. Research Methods

### *1. Designing a Transition Metallic Catalytic Converter*

Designing a TMCC is shown in Figure 1. The TMCC utilizes copper-coated chrome (CuCr) as the catalyst material. The TMCC configuration consists of a tube diameter (TD) of 60.8 mm, tube length (TL) of 88.1 mm, and curvature height (CH) of 3.5 mm. Additionally, the inlet angle (IA) casing is designed with a 12°, and the outlet angle (OA) casing is designed with a 22° [9].

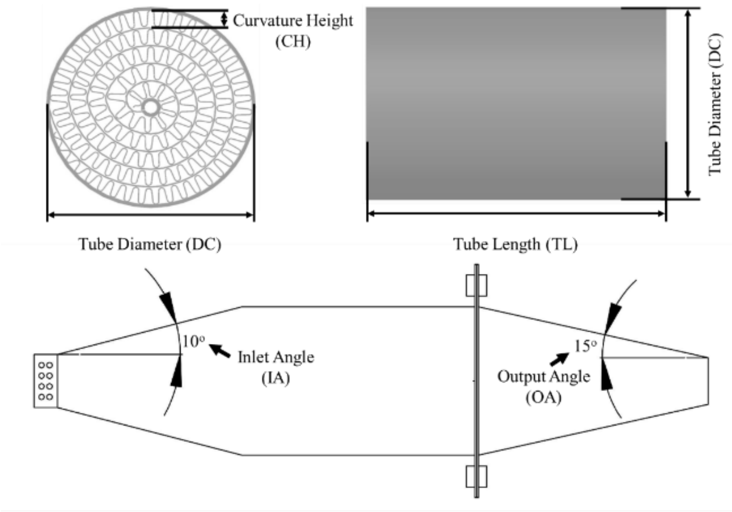


Fig. 1. TMCC configuration

*2. Experimental Process*

There are three types of exhaust systems tested: STD WC, STD OEM, and TMCC CuCr. These three exhaust systems were implemented on a sports motorcycle. The testing process covered various rpm, ranging from idle to 9000 rpm, following the SNI 7554: 2010 standard [10]. Fuel consumption, as the primary parameter, is measured using a fuel consumption measurement device connected to the fuel pump of the sports motorcycle. In greater detail, the research instrument is depicted in Figure 2.

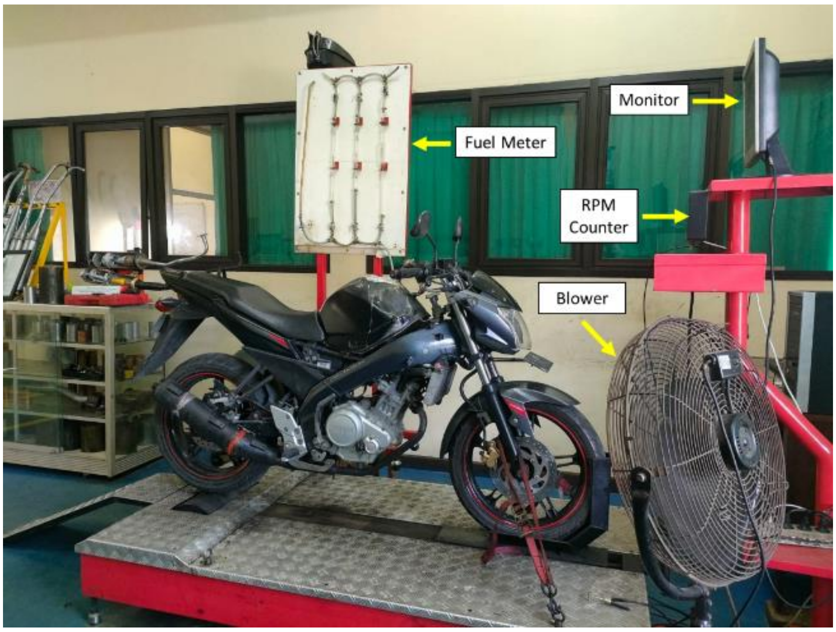


Fig. 2. Research instrument

The fuel consumption test data obtained represents the time it takes for the test vehicle to consume 5 ml of fuel at each engine rpm level. Equation 1 was then utilized to convert this data such that test results in liters per hour could be obtained.

$$FC\ (l/h) = \frac{V_f}{t}\ x\ \rho\ x\ \frac{3600}{1000} \qquad (1)$$

*3. Data Analysis Techniques*

The quantitative descriptive data analysis method was used in this study. The information gathered comprises of numbers that show the amount of fuel consumed at each rpm for each kind of exhaust system [11]. For obtaining numerical data about fuel economy and consistency, the study comprises computing the mean and standard deviation. As a clearer visual representation, the data is also offered in tabular and graphical formats.

## III. Results and Discussions

The findings of the fuel consumption tests serve as an example of how each type of exhaust system employed in the testing process compares in terms of efficiency. Table 1 shows the results of the fuel consumption testing. For each rpm and all types of exhaust systems, fuel consumption experiments were performed using a pipette with a volume of 5 ml.

**Table 1.** Fuel consumption (total time to consume 5 ml of fuel)

| RPM | STD WC | | STD OEM | | TMCC CuCr | |
|---|---|---|---|---|---|---|
| | Minutes | Seconds | Minutes | Seconds | Minutes | Seconds |
| 1500 | 6 | 28 | 9 | 5 | 8 | 45 |
| 2000 | 4 | 20 | 8 | 14 | 7 | 33 |
| 3000 | 2 | 10 | 4 | 27 | 5 | 55 |
| 4000 | 1 | 15 | 3 | 32 | 3 | 30 |
| 5000 | 1 | 4 | 2 | 34 | 2 | 23 |
| 6000 | 0 | 54 | 2 | 15 | 2 | 12 |
| 7000 | 0 | 48 | 1 | 55 | 1 | 45 |
| 8000 | 0 | 42 | 1 | 41 | 1 | 37 |
| 9000 | 0 | 36 | 0 | 59 | 0 | 56 |

Table 1 presents fuel consumption data for sport motorcycles at various rpm in three different conditions: STD WC, STD OEM, and TMCC CuCr. To delve deeper into understanding these results, let's examine the observed trends. It is clear that using TMCC CuCr results in more efficient fuel usage when compared to regular exhaust systems, including STD WC and STD OEM, at low rpm, like 1500 and 2000 rpm. This is related to TMCC technology's ability to enable more effective combustion and precise fuel injection regulation. These results support Ilyas et al. research [12], which shows that accurate fuel injection can raise internal combustion engines' efficiency. Additionally, the usage of throttle valves and catalytic technologies can affect fuel consumption, according to the Teodosio et al. study [13].

Unfortunately, the difference in fuel consumption between TMCC CuCr and normal exhaust systems decreases as rpm increases, such as at 8000 and 9000 rpm. This might mean that the efficiency advantages of TMCC CuCr at high rpm are no longer as relevant. These findings concur with a study by Sriyanto et al. [14], which found that fuel injection technology does not necessarily result in a significant increase in efficiency at high rpm. It's crucial to keep in mind that a vehicle will use less fuel when it burns it more slowly. This is due to the fact that variations in rpm, both high and low, can reduce the duration of combustion and produce fluctuations in fuel consumption in internal combustion engines [15]. In other words, a vehicle gets more fuel-efficient as the time it takes for fuel to burn is longer [16]. Furthermore, the use of catalytic converters can also affect a vehicle's fuel economy, as found in previous research by Naufal et al. [17]. The influence of this can vary depending on the type of catalytic converter, material composition, and other research-related factors [18]. However, in order to calculate the degree of efficiency, the results of fuel consumption tests must be converted into liters per hour using Equation 1. Table 2 displays the results of this conversion.

**Table 2.** Fuel consumption (in liters per hour)

| RPM | STD WC (liters/hour) | STD OEM (liters/hour) | TMCC CuCr (liters/hour) |
|---|---|---|---|
| 1500 | 0.03 | 0.02 | 0.02 |
| 2000 | 0.05 | 0.03 | 0.03 |
| 3000 | 0.10 | 0.05 | 0.04 |
| 4000 | 0.17 | 0.06 | 0.06 |
| 5000 | 0.20 | 0.08 | 0.09 |
| 6000 | 0.24 | 0.10 | 0.10 |
| 7000 | 0.27 | 0.11 | 0.12 |
| 8000 | 0.31 | 0.13 | 0.13 |
| 9000 | 0.36 | 0.22 | 0.23 |
| Average | 1.74 | 0.80 | 0.83 |
| Standard Deviation | 0.11 | 0.06 | 0.07 |

Based on the data in Table 2, when presented in the form of a graph, it can be seen in Figure 3. The graph illustrates the trend of fuel consumption at each rpm for all types of exhaust systems. In Figure 1, the x-axis represents engine rpm, while the y-axis represents fuel consumption in liters per hour.


Fig. 3. Trends in fuel consumption at each rpm

The data from the fuel consumption measurements in Table 2 provides an interesting insight into the impact of TMCC on fuel consumption. This TMCC is made of CuCr-plated copper sheet with a thickness of 0.15 mm and features a honeycomb design with 3.5 mm curvature high on a 60.8 mm diameter tube. As explained by Sheldon & Dua [19], lower average fuel consumption indicates higher efficiency of the vehicle in covering a certain distance. Additionally, according to Xu [20], the standard deviation reflects the consistency of fuel consumption at each rpm, where a smaller standard deviation signifies more consistent fuel consumption. The test results indicate that the average fuel consumption for STD OEM is 0.80 liters per hour, whereas for TMCC CuCr, it is 0.83 liters per hour. The standard deviation for STD OEM is 0.06, whereas for TMCC CuCr, it is 0.07. Therefore, it can be concluded that STD OEM is the preferred choice because it has a lower average fuel consumption and a smaller standard deviation compared to TMCC CuCr.

From a mechanical perspective, the TMCC structure is designed with a honeycomb type to provide a larger surface area. The inlet (IA) and outlet (OA) angles are set at 12° and 22°, respectively, to control the accumulation of exhaust gases within the casing [21]. From a chemical standpoint, the increased surface area of the catalyst, particularly the chromium layer on the copper sheet CuCr, significantly influences the redox reaction between exhaust gases and the catalyst [22]. Meanwhile, the adjustment of IA and OA angles induces turbulence, leading to increased backpressure, where pressurized exhaust gases are forced back into the combustion chamber when both valves open simultaneously (overlapping), as illustrated in Figure 4 [23]. This is intended to maintain the combustion chamber temperature at an optimal operating condition, resulting in improved combustion efficiency and fuel savings [24]. However, measurement results indicate that TMCC CuCr tends to have a slightly higher fuel consumption compared to STD OEM, possibly due to the superior quality of raw materials used in STD OEM, which includes precious metals.

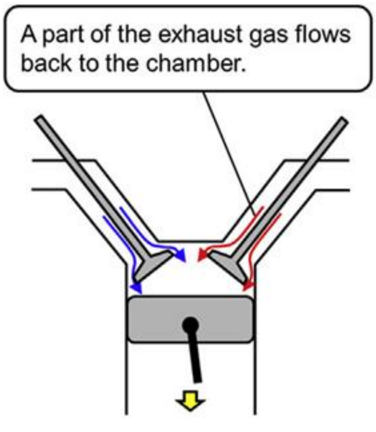


Fig. 4. Valve overlap in internal combustion engine [25]

These findings are supported by previous research. Warju et al. [6] revealed that the use of honeycomb-structured catalysts can significantly reduce pollutant emissions from motor vehicles. This finding aligns with the results found by Patil and Chaudhary [26], which showed that increasing the catalyst surface area can enhance pollutant conversion efficiency while reducing vehicle power loss. Additionally, Dey and Kumar [27] demonstrated that the use of catalytic converters with chromium coatings can positively impact exhaust gas conversion efficiency. Hosseini et al. [28] also support this idea by showing that the honeycomb design facilitates a significant increase in surface area for catalytic reactions, allowing for a more efficient oxidation process of CO emissions into $CO_2$. On the other hand, research by Yang et al. [29] presented relevant findings, indicating that proper inlet and outlet angle adjustments can improve combustion efficiency and reduce fuel consumption in vehicles. Similar research by Shah et al. [30] revealed that increased backpressure due to overlapping can have a positive effect on more complete combustion. Another study conducted by Luo et al. [31] further verified that adjusting the inlet and outlet angles can lead to improved combustion efficiency and reduced emissions of toxic exhaust gases.

Following the previous discussion, fuel inefficiency is a factor that needs to be considered when using exhaust systems equipped with catalytic converters. However, there are additional considerations, namely the type of material used and the price of the exhaust system. STD OEM exhaust systems use precious metals that are relatively expensive, while TMCC CuCr exhaust systems use transition metal materials (CuCr) that are more affordable. In this context, if fuel efficiency is the primary factor and the difference in mean fuel consumption of 0.03 liters per hour with a standard deviation of 0.01 between the two is considered significant, then STD OEM exhaust could be the best choice despite the higher cost of materials. However, Ariyanto et al. [18] provide a perspective that if the difference in fuel consumption is considered insignificant and price is an important consideration, then TMCC CuCr with cheaper transition metal materials and more abundant availability could be a more economical option.

## IV. Conclusions

Based on the research results of fuel consumption for three types of exhaust systems, namely STD WC, STD OEM, and TMCC CuCr, several important findings have emerged. STD OEM shows a lower mean fuel consumption (0.80 liters per hour) compared to TMCC CuCr (0.83 liters per hour) and STD WC (1.74 liters per hour). STD OEM also has a smaller standard deviation (0.06) compared to TMCC CuCr (0.07) and STD WC (0.11), indicating better consistency in fuel consumption at each rpm. The type of material employed and the exhaust system's cost should both be taken into account when selecting the ideal exhaust system. While TMCC CuCr employs less expensive copper-coated chrome transition metal components, STD OEM uses somewhat pricey precious metals.

In terms of fuel efficiency, STD OEM is the best option based on the mean and standard deviation figures. However, TMCC CuCr emerges as a compelling alternative if the difference in mean fuel usage of 0.03 liters per hour and a marginally larger standard deviation (0.01) are deemed unimportant. The advantages of TMCC CuCr include lower prices and larger availability of raw materials. Furthermore, it performs similarly to STD OEM in terms of fuel consumption.

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