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The effect of copper thickness in catalytic converters on HC and CO emissions

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Abstract

Advances in transportation technology has significantly increases human mobility and supported economic growth, however it has also led to a rise in harmful exhaust emissions, which adversely affect air quality and contribute to climate change. To address this, it is essential to minimize exhaust emissions, one effective method being the use of catalytic converters. This study aims to investigate the effect of copper thickness, specifically variations of 0.2 mm, 0.5 mm and 0.7 mm as the basic material of catalytic converters. Experimental research using Honda Vario 125 motorized vehicles operating on Pertalite fuel, with emissions measured at varying engine speeds from 1500 rpm to 7000 rpm. The QROTECH QRO 401 gas analyzer was utilized to assess HC and CO exhaust emissions. The results indicate that the thickness of copper used in catalytic converters can effectively reduce CO and HC emissions. Specifically, the sample with a copper thickness of 0.7 mm demonstrated an average CO emission of 0.36% and a standard deviation of 0.0015, while the HC emission produced an average of 112 ppm with a standard deviation of 14.85.

Keywords:
Catalytic converter, copper, exhaust emissions.

1 Introduction

As technology advances, productivity in various fields is increasing, especially in the transportation sector that uses fuel oil with an internal combustion process in combustion engines. Combustion engines are machines that convert heat energy into mechanical energy. Exhaust emissions are the remaining results of fuel combustion in internal combustion engines [1], the formation of vehicle exhaust emissions when the engine is running due to imperfect combustion caused by insufficient or excessive air and fuel mixture conditions [2]. One common method used to reduce exhaust emissions is by using a catalytic converter in the vehicle's exhaust system.

A catalytic converter is a device installed on the exhaust pipe that functions to reduce gas emissions from incomplete fuel combustion so that when the gas exits the exhaust pipe the level of exhaust gas emissions is reduced, to reduce exhaust gas emissions, a copper catalytic converter is used, apart from being more affordable, it can also be used as an oxidation catalyst and reducing catalyst to reduce the concentration of CO and HC in exhaust gas [3].

The catalyst is made from commercially pure copper with 99.9% Cu formed into a corrugated structure without additional coatings or chemical treatments. This design takes advantage of copper's inherent catalytic properties for oxidation-reduction reactions, as demonstrated in previous research [4][5].

The effectiveness of a converter catalyst in reducing exhaust emissions is significantly influenced by its design and material composition. One critical parameter is the thickness of the copper used as the catalyst. Varying copper plate thicknesses can impact the surface area available for catalytic reactions and thus affect the efficiency of exhaust emission conversion. Additionally, engine rotational speed plays a vital role in determining operating conditions. Different rotational speeds can lead to variations in temperature and exhaust gas residence time within the catalytic converter, which subsequently influences the effectiveness of emission reduction.

The use of a honeycomb-shaped copper catalytic converter has been shown to reduce exhaust gas emission levels, achieving the highest CO reduction at 4000 rpm, while the most significant reduction in HC emissions occurs at the same speed, with a value of 73 ppm [6]. The use of copper plates thicker than 0.3 mm with widened honeycomb fins will encourage higher exhaust gas rates [7][8].

The use of geometric optimization of a copper-based catalytic converter resulted in CO emissions of 3.72% vol and HC emissions of 539 ppm. This study validated the performance of copper-based catalysts, which are capable of potentially reducing emissions or controlling exhaust emissions [9].

Therefore, this study aims to investigate the effect of copper thickness used as a catalytic converter on exhaust gas emissions.

2 Research methodology

The data collection method applied in researching exhaust gas refers to no-load testing on the engine [10]. The experimental method with the dependent variable being CO and HC gas emissions, while the independent variables were the thickness of copper as a catalyst converter, variations in engine rotation speed and Pertalite type fuel. The technical specifications of the test engine used in this study are shown in Table 1.

Table 1. Technical specifications

Engine specifications	Description
Engine type	4 Stroke
Volume	125 cc
Machine configurations	Single cylinder
Fuel system	Injection
Fuel	Pertalite
Bore × stroke	52.4 mm × 57.9 mm
Compression ratio	11:1
Maksimum power	11.3 ps / 8500 rpm
Maksimum torque	1.1 kgf.m /5000 rpm
Lubrication system	Wet lubrication

Table 1 presents the technical specifications of the Honda Vario 125 engine utilized in this study. This engine type is commonly referenced in small-scale experimental studies on emission reduction due to its representation of a typical four-stroke gasoline engine configuration equipped with Electronic Fuel Injection (EFI). The engine features a single-cylinder design with an air-cooling system, a displacement of 124.8 cc, and a compression ratio of 11:1, enabling efficient operation under medium-speed combustion conditions.

The engine achieves maximum power and torque outputs of 8.2 kW at 8,500 rpm and 10.8 Nm at 5,000 rpm, respectively, which are characteristic of modern scooter engines employed in urban transportation. The fuel system utilizes an EFI mechanism, ensuring precise control of the air-fuel mixture during combustion, which is essential for analyzing exhaust gas emissions such as Hydrocarbons (HC) and Carbon Monoxide (CO).

Additional specifications, including the ignition type (full transistorized), bore and stroke ratio, and transmission system, establish a realistic baseline for evaluating the impact of the copper converter catalyst integrated into the exhaust system. The selection of this engine specification facilitates consistent data comparison, reduces performance variation due to external factors, and ensures that any observed emission reductions can be directly attributed to the catalytic performance of copper rather than alterations in engine operation.

In summary, Table 1 offers a comprehensive overview of the engine's operational characteristics, which serve as the foundation for subsequent emission testing and performance analysis throughout this research.

2.1 Testing and measurement

Measurement of exhaust gas emission levels refers to the SNI 09-7118.3-2005 standard [11]. A gas analyzer measuring instrument with the specifications in Table 2 is integrated with a catalyst converter. As shown in Fig. 1, the gas analyzer is positioned connected to the exhaust gas duct to analyze the resulting emissions content. The main focus of the analyzed emissions is CO and HC.

Fig. 1. Exhaust gas emission measurement installation.

Table 2. Exhaust gas analysis tool specifications

Information	Description
Brand	QROTECH QRO 401
Voltage	AC 220 V 60 Hz
Operating range	Co 0-9,99% Hc 0-9999 ppm
Operating temperature	0–40°C

Table 2 presents the specifications of the exhaust gas analyzer utilized in this study. The measurement instrument employed was a QROTECH QRO 401 gas analyzer, which operates at an AC voltage of 220 V and a frequency of 60 Hz. This device can detect CO concentrations ranging from 0 to 9.99% and HC up to 9999 ppm, making it suitable for testing the exhaust emissions of small gasoline engines, such as the Honda Vario 125 used in this experiment.

The analyzer operates within a temperature range of 0°C to 40°C, ensuring stable measurement performance under laboratory and workshop conditions. Its high sensitivity and precision facilitate the accurate detection of even minor variations in exhaust gas concentrations, which is essential for evaluating the effect of the copper converter catalyst installed in the exhaust pipe.

Based on the specifications provided in Table 2, the QROTECH QRO 401 is an appropriate instrument for emission characterization, as it delivers reliable and consistent readings for both CO and HC gases. The use of this analyzer ensures that the data collected during the testing phase accurately reflects the combustion quality and emission characteristics of the engine under various test conditions.

As indicated in Table 2, the QROTECH QRO 401 gas analyzer was employed to measure exhaust emissions during testing with precision. To conduct a comprehensive evaluation, the motorcycle was securely positioned in an open-air testing area to ensure proper exhaust ventilation and safety. Data collection involved installing the copper catalytic converter with varying plate thicknesses of 0.2 mm, 0.5 mm, and 0.7 mm within the exhaust system.

Each measurement was conducted at engine speeds ranging from 1,500 rpm to 7,000 rpm, with every speed held steady for 60 seconds to ensure stable combustion and consistent exhaust flow. For accuracy and repeatability, data were recorded three times at each engine speed. This procedure allowed for the identification of performance trends and emission characteristics under different catalyst configurations.

2.2 Data analysis

Data processing was carried out using descriptive statistical analysis. The average and standard deviation values for each sample were calculated to determine the consistency of each sample data result [12]. To find out how the significant influence of the copper-based catalytic converter system with plate thickness variations between 0.2 mm, 0.5 mm and 0.7 mm on the levels of CO and HC exhaust emissions, can be done using the one-way variance test method [13].

3 Results and discussion

Based on the tests carried out, the following are the results of research data after testing with the installation of a catalytic converter with a material thickness of 0.2 mm, 0.5 mm, 0.7 mm and conditions without a catalytic converter or factory standard show in Table 3.

Table 3. CO exhaust emission data

Engine speed (rpm)	CO			
	Std	0.2 mm	0.5 mm	0.7 mm
1500	0.77%	0.68%	0.74%	0.65%
2000	0.64%	0.56%	0.58%	0.44%
3000	0.59%	0.47%	0.53%	0.38%
4000	0.40%	0.38%	0.38%	0.33%
5000	0.31%	0.24%	0.26%	0.31%
6000	0.28%	0.21%	0.24%	0.25%
7000	0.27%	0.25%	0.15%	0.15%
Average	0.47%	0.40%	0.41%	0.36%
$S_{deviation}$	0.0019	0.0017	0.0020	0.0015

Table 3 presents the results of CO exhaust emission measurements at various engine speeds for both the standard condition (without catalyst) and the installation of copper catalytic converters with thicknesses of 0.2 mm, 0.5 mm, and 0.7 mm. The data show a clear reduction trend in CO emissions when the copper catalyst is applied, compared to the standard exhaust condition.

At low engine speeds (1,500–3,000 rpm), CO emissions are relatively high for all conditions due to incomplete combustion and lower exhaust gas temperature. The standard configuration recorded the highest CO value of 0.77% at 1,500 rpm, while the use of a 0.7 mm copper catalyst reduced CO to 0.65%, representing a reduction of approximately 15.6%. As engine speed increases to 3,000 rpm, the CO level decreases for all conditions, indicating improved combustion efficiency.

In the mid to high rpm range (4,000–7,000 rpm), CO emissions continue to decline significantly. The 0.7 mm catalyst plate produced the lowest average CO concentration of 0.36%, followed by the 0.2 mm and 0.5 mm catalysts at 0.40% and 0.41%, respectively, compared to the standard condition with 0.47%. The standard deviation ($S_{deviation}$) values, which are relatively small (0.0015–0.0020), indicate that the data obtained are consistent and reproducible.

Overall, the application of the copper catalytic converter effectively reduced CO emissions across all engine speeds, with the best performance achieved using a plate thickness of 0.7 mm. This reduction is attributed to the increased catalytic surface area and higher oxidation efficiency, promoting the conversion of CO into CO_2 during the exhaust gas flow.

From the results of the catalytic converter CO emission test, the effect in reducing CO can be seen from the average value of CO gas emissions and the standard deviation value. The average emission shows the average level of emissions produced in each test, while the standard deviation is used to determine the distribution of data around the average. The lower the average value and standard deviation, the better and more consistent in reducing CO gas emissions. Therefore, the best catalytic converter from the sample data obtained an average value of 0.36% and a standard deviation of 0.0015 at a catalytic converter thickness of 0.7 mm. The relationship between CO exhaust emissions and engine speed is illustrated in Fig. 2.

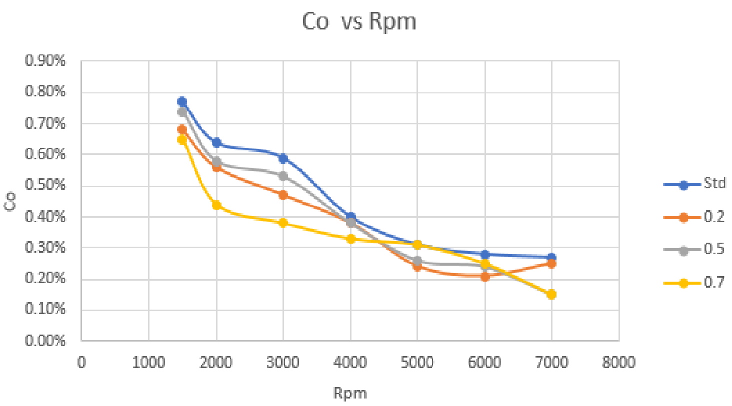

Fig. 2. CO exhaust emission vs rpm.

The emission graph in Fig. 2, depicting CO levels versus rpm, demonstrates that the catalytic converter integrated with a 0.7 mm copper plate effectively reduces CO emissions to 0.36% at 5000 rpm, which is lower than the standard level of 0.47% observed without a catalyst. The decline in CO emissions with increasing rpm suggests that catalyst efficiency is influenced by exhaust gas temperature and the reaction surface area. These findings support the conclusions of Warju et al. (2024) regarding the necessity of optimizing catalyst thickness, although CuCr material remains superior in emission stability. Additionally, the graph indicates a rise in CO emissions at certain rpms, attributed to suboptimal combustion processes characterized by insufficient oxygen (O_2). Conversely, a decrease in CO emissions suggests that oxygen levels are nearly adequate for the combustion process, a finding that aligns with the research conducted by Arianto [14].

The factor causing the incomplete combustion process is the back pressure of the exhaust gas caused by the gas flow hitting the wall of the catalyst area so that the exhaust gas flow is blocked. The higher the back pressure that occurs in the exhaust gas, the greater the potential to reduce the efficiency of ideal engine combustion. This is because the back pressure of the exhaust gas allows the remaining gas to be pushed back into the combustion chamber so that the combustion chamber lacks O_2 during the combustion process, whereas when exhaust gas emissions decrease, it means that the O_2 requirement is met during the combustion process. From the results, when comparing CO exhaust gas emissions with the addition of a copper-based catalytic converter, it tends to show lower CO emissions when compared to without a catalytic converter. With the addition of a copper-based catalytic converter, it results in a decrease in CO exhaust gas emissions due to the oxygen binding reaction, when CO exhaust gas emissions pass through the copper catalyst, the reaction process between CO and O_2 will be more effective due to the characteristics of copper as an oxidation catalyst, so that CO exhaust gas emissions can be converted into harmless gases [15][16]. The HC exhaust emission data obtained from the experiment are summarized in Table 4.

Table 4 presents HC exhaust emission data obtained from tests conducted at various engine speeds and catalyst thicknesses (0.2 mm, 0.5 mm, and 0.7 mm), compared with standard conditions without a catalytic converter. The results indicate a general trend of decreasing HC concentration as engine speed increases across all configurations. This reduction can primarily be attributed to more complete combustion and higher exhaust gas temperatures at elevated rpm, which enhance oxidation efficiency.

Table 4. HC exhaust emission data

Engine speed	HC			
(rpm)	Std	0.2 mm	0.5 mm	0.7 mm
1500	169	163	138	141
2000	149	141	125	124
3000	138	133	102	115
4000	121	113	100	108
5000	120	106	97	103
6000	112	104	87	98
7000	108	102	83	96
Average	131	123	105	112
$S_{deviation}$	20.45	21.43	18.49	14.85

At low engine speeds (1,500–3,000 rpm), HC emissions are relatively high due to limited combustion temperature and turbulence, resulting in incomplete fuel oxidation. Under standard conditions, HC concentration reaches 169 ppm at 1,500 rpm; however, the installation of a 0.5 mm copper catalyst reduces this concentration to 138 ppm, corresponding to an improvement of approximately 18.3%.

As engine speed increases to 4,000–7,000 rpm, HC emissions continue to decline significantly across all catalyst thicknesses. Among the tested samples, the 0.5 mm copper catalyst yields the lowest average HC value of 105 ppm, followed by 0.7 mm (112 ppm) and 0.2 mm (123 ppm), while the standard configuration records an average of 131 ppm.

The small standard deviation values (ranging from 14.85 to 21.43) indicate that the measurements are consistent and reproducible. These findings suggest that the use of a copper catalytic converter enhances the oxidation of unburned hydrocarbons, particularly at medium and high engine speeds where the temperature of the exhaust gas is sufficient to activate the catalytic reaction.

Overall, Table 4 demonstrates that the copper-based catalyst can significantly reduce HC emissions compared to the standard exhaust, with the 0.5 mm thickness providing the optimal balance between surface area and exhaust flow resistance. The relationship between HC exhaust emissions and engine speed is illustrated in Fig. 3.

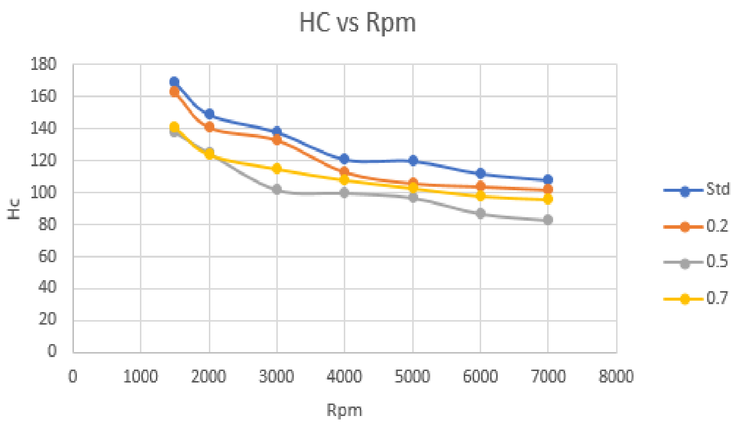

Fig. 3. HC exhaust emission vs rpm.

The data show that the thickness of the copper plate significantly affects the catalytic efficiency. For CO emissions in Table 3, a thickness of 0.7 mm provides the highest reduction (0.36% vs. the standard 0.47%) due to increased active surface area and optimal temperature retention. Meanwhile, for HC, a thickness of 0.5 mm is superior (105 ppm vs. 131 ppm) with a gas residence time suitable for hydrocarbon oxidation without increasing excessive backpressure. This finding is consistent with mass transport theory where the optimal thickness differs for each type of emission due to differences in reaction mechanisms [17].

Based on Fig. 3, HC exhaust emissions experience a graphical decrease with each increase in rpm and do not show a relatively high increase. If there is an increase in the value of HC exhaust emissions, this is due to an incomplete combustion process because there is fuel that is not burned during the combustion process. As previously explained, one of the factors causing incomplete combustion is due to the back pressure of exhaust gases, the back pressure of exhaust gases is caused by the gas flow hitting the catalyst area and eventually clogging. The decrease in HC exhaust emissions occurs due to the oxidation process of HC compounds assisted by the copper catalyst reaction, where the oxidation reaction is the binding of oxygen, when HC exhaust emissions pass through the copper catalyst, the reaction process between HC and O_2 due to the characteristics of copper as an oxidation catalyst, so it will be more effective and produce harmless exhaust emissions [18][19].

The results of this study reinforce previous research on the use of alternative metal-based materials. As a comparative analysis, several researchers have examined the use of copper-based catalysts in catalytic converters. In the study by Irawan et al [20] study on the optimal design of a copper (Cu) manganese coated catalytic converter aimed to reduce CO emissions from exhaust gases. The results showed an optimized reduction in CO emissions. Shoffan et al.'s study [21] showed that the addition of a copper-based catalytic converter with a circular tube model could reduce HC emissions by 32.54% and CO emissions by 16.67%. In Warju et al.'s study [22] using the application of copper (Cu) and chromium coated catalysts in a metal catalytic converter, and showed a significant reduction in CO and HC emissions from a four-stroke gasoline engine with the use of a Cu+Cr metal catalytic converter.

The application of catalytic converters can have a positive impact on maintaining air quality and environmental impact. Based on the findings of this study, the importance of using catalytic converters as a tool to reduce harmful emissions and improve air quality has been identified.

4 Conclusions

This study investigates the impact of copper plate thickness (0.2 mm, 0.5 mm, and 0.7 mm) as the base material for catalytic converters on the reduction of CO and HC exhaust emissions in a Honda Vario 125 motorcycle. The experimental results yielded the findings: a copper plate thickness of 0.7 mm achieves optimal CO emission reduction, averaging 0.36% (standard deviation: 0.0015), compared to 0.47% without a catalyst. The 0.5 mm plate thickness is most effective in reducing HC emissions, averaging 105 ppm (standard deviation: 18.49), relative to standard conditions at 131 ppm. Catalytic efficiency increases with engine rpm (1500–7000 rpm), with the most significant emission reductions occurring between 4000 and 7000 rpm, attributed to elevated exhaust gas temperatures and adequate gas residence time for oxidation reactions. Copper functions as an oxidation catalyst by binding oxygen (O_2) to convert CO and HC into less harmful compounds (CO_2 and H_2O). However, suboptimal catalyst design may lead to backpressure, which can diminish combustion efficiency. The practical application of copper as a catalytic converter material presents an economical solution for emission control, particularly in developing countries with limited access to costly materials such as platinum. Further research is necessary to explore copper thicknesses beyond the 0.2–0.7 mm range and to investigate combinations with other methods to optimize performance.

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