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Exhaust Emission Control In Sport Motorcycles: Acomparison Of Catalytic Converters With Alternative Metal Materials

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Abstract

In this modern era, motor vehicles have brought significant changes in human life. Faster and more efficient mobility has increased connectivity between regions, supported economic growth, and improved quality of life. However, increased mobility also means an increase in vehicle exhaust emissions, which contribute to climate change and air pollution. One effective technology for controlling exhaust emissions is the use of catalytic converters. Metal catalytic converters, such as copper, brass, and chrome-plated copper, have been researched as more affordable and effective catalyst alternatives. This research aims to analyze the optimal design of exhaust systems with catalytic converters among three types of alternative materials (copper, brass, and chrome-plated copper) as well as standard exhaust systems without catalysts (STD NC) and standard platinum group metal exhaust systems (STD PGM) in maximizing the reduction of motor vehicle exhaust emissions. An experimental research design was used by utilizing a 2015 Yamaha Vixion Lightning as the research object. Catalytic converters were prepared with specific specifications to ensure consistency and accuracy in measurements. Carbon monoxide (CO), hydrocarbons (HC), carbon dioxide(CO_2), and oxygen (O_2) emissions were analyzed using an exhaust gas analyzer. The research results indicate that the CuCr sample exhibits excellent performance in reducing CO and HC emissions. The CuCr sample has an average CO emission of 4.09% Vol with a standard deviation of 1.46, demonstrating good consistency in CO emissions. Meanwhile, the average HC emissions from the CuCr sample are 320 ppmVol with a standard deviation of 106, indicating good consistency in HC emissions. All samples meet the emission standards set by the government, except for the STD NC sample, which exceeds the CO emission threshold.

Keywords:
Motor vehicles, exhaust emissions, catalytic converter, copper, brass, chrome-plated copper.

1 Introduction

In this modern era, motor vehicles have brought significant changes to human life [1]. Faster and more efficient mobility has increased interregional connectivity, economic growth, and quality of life. However, increased mobility also means increased vehicle exhaust emissions, which contribute to climate change and air pollution [2]. One of the major contributors to air pollution is motor vehicles, which emit various toxic compounds that can potentially damage the environment. Therefore, reducing exhaust emissions from motor vehicles is an urgent need [3].

In response to these challenges, various technologies and solutions have been developed to reduce exhaust emissions from motor vehicles. One effective technology for controlling exhaust emissions is the use of catalytic converters [4]. Catalytic converters are used to convert toxic compounds in vehicle exhaust gases into safer and harmless compounds. The unique catalytic properties enable effective chemical reactions to convert toxic gases into safer compounds, thereby impacting emission control and overall engine efficiency [5].

Metal catalytic converters are one of the most used types of converters in motor vehicles. Metal catalytic converters utilize metal-based catalysts such as platinum, palladium, and rhodium to facilitate chemical reactions that transform harmful compounds in exhaust gases into less toxic compounds [6]. However, the use of these precious metals as converter catalysts is expensive and limited in natural resources. Therefore, research has been conducted to seek more affordable and effective catalyst alternatives [7].

Several previous studies have investigated the use of non-precious metals such as copper (Cu) and brass as catalysts in converters. Shoffanet al.[1] found that the use of copper-based converter catalysts successfully reduced CO emissions by 16.67% and HC emissions by 32.54% in motorcycle engines. Irawan et al. [8] found that the use of manganese-coated copper converter catalysts significantly reduced carbon monoxide emissions in gasoline engines. EllyanieandOktabri[9] reported that the addition of brass-based (CuZn) converter catalysts can increase engine torque and power while reducing fuel consumption. Warjuet al.[10] examined the performance of chrome-plated copper converter catalysts, which resulted in a significant reduction in CO and HC emissions. These studies indicate that copper and brass have good catalytic activity in reducing exhaust emissions [11]. Additionally, research has also shown that the chrome layer on copper can enhance its catalytic efficiency [12].

Knowledge about the characteristics and performance of metal catalytic converters is important in optimizing system design and efficiency [13]. Factors such as the number of catalyst cells, backpressure, and thermal efficiency play a significant role in influencing the performance of catalytic converters [14]. A better understanding of how these metals interact with exhaust gases and affect engine performance can assist in the development of more efficient and sustainable catalytic converter technologies.

However, despite several studies have examined the use of copper, brass, and copper-chromium alloys as catalysts in converters, there has been no comprehensive study comparing the effectiveness of metal converter catalysts made from copper, brass, and copper-chromium alloys in reducing exhaust emissions from motor vehicles. Therefore, the primary objective of this research is to analyze the design of exhaust systems with the most optimal catalytic converter among these three alternative materials (copper, brass, and copper-chromium alloys). Furthermore, this design will be compared with both the standard exhaust system without a catalyst (STD NC) and the standard exhaust system with noble metals or platinum group metals (STD PGM) in an effort to achieve maximum reduction of motor vehicle exhaust emissions. By comprehending the capabilities of each design, the most effective design can be identified for reducing exhaust emissions and developing a catalytic solution that is more efficient and affordable [15].

2 Research Method

2.1 Experiment Design and Research Object

In this study, an experimental research design was used to analyze the effectiveness of metal catalytic converters in improving exhaust gas emission control. The independent variables in this study are the types of metal catalytic converters, including copper, brass, and chrome-plated copper. Meanwhile, the dependent variable is the level of exhaust gas emissions generated. This research is conducted in a controlled setting designed to ensure consistency and accuracy in measurements.

The research object used is a Yamaha Vixion Lightning (Table 1). The Yamaha Vixion Lightning was chosen as the research object because it is one of the popular motor-cycles with many users. The selection of the research object relevant to the research topic is important to ensure that the research findings can be applied and have practical value in the context of exhaust gas emission control.

Table 1. Technical specifications

Engine specifications	Description
Engine type	4-stroke, SOHC FI
Engine displacement	149.8 cc
Cylinder configuration	Single cylinder
Fuel system	Fuel injection
Lubrication system	Wet
Maximum torque	14.5 Nm/7.500 rpm
Maximum power	8.97 HP/8.500 rpm
Compression ratio	10.4 : 1
Bore × stroke	57.0 mm × 58.7 mm
Cooling system	Liquid cooled

2.2 Catalytic Converter Specification

The Catalytic Converters used in this study consist of copper, brass, and chrome-plated copper. These three converters were prepared with specifications including a catalyst curve height of 2 mm, a catalyst diameter of 54 mm, and a catalyst length of 100 mm (Fig. 1). The purpose of these specifications is to ensure uniformity and consistency in each converter used.

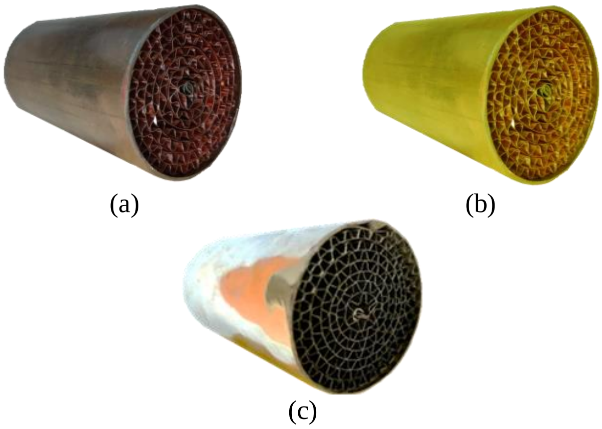

Fig. 1. Catalytic converter made of (a) copper, (b) brass, and (c) chrome-plated copper.

2.3 Measurement and Test Equipment

To measure exhaust emissions accurately, an exhaust gas analyzer is used with the specifications shown in Table 2. This crucial device is intricately linked to the motorcycle's exhaust system, specifically integrated with the muffler or catalytic converter within the exhaust system. As depicted in Fig. 2, the exhaust gas analyzer is strategically positioned to monitor and analyze exhaust gas emissions, focusing primarily on pollutants such as carbon monoxide (CO) and hydrocarbons (HC). This analysis aids in comprehending the environmental impact and performance of the Yamaha Vixion Lightning motorcycle.

Table 2. Exhaust gas analyzer specifications

Information	Description
Brand	HeshbonHG-520
Voltage	220/240Vac 50/60H
Operation range	0-9.99% with 0.01% resolution

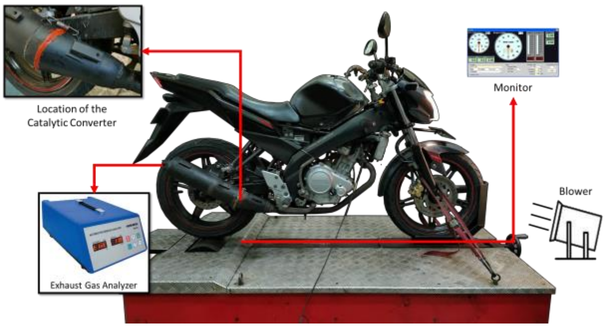

Fig. 2. Measurement and test equipment.

During the comprehensive testing procedure, the Yamaha Vixion Lightning motorcycle was securely positioned on a specialized chassis dynamometer. The chassis dynamometer plays a pivotal role in the experiment by subjecting the engine to varying loads, effectively emulating real-world riding scenarios and conditions. This dynamic setup facilitates measurements at precise 1000 RPM intervals, spanning across the entire spectrum from idle RPM to a robust 9000 RPM. The methodical use of the exhaust gas analyzer and the chassis dynamometer ensures the acquisition of detailed and accurate emission data, instrumental for making informed assessments about the motorcycle's emissions profile and environmental impact.

2.4 Data Analysis Technique

The data analysis technique used in this study is descriptive statistical analysis. In this analysis, data obtained from CO, HC, CO_2, and O_2 emissions testing on various samples of catalytic converters are evaluated qualitatively [16]. Mean and standard deviation measurements are calculated for each emission parameter to assess the performance and consistency of each sample. The mean values depict the average level of emissions produced by each catalytic converter sample, while the standard deviation indicates the variation of emissions around the mean.

Furthermore, the emission data from each sample is compared to the emission standards set by the government to evaluate compliance with environmental regulations. If the emissions of a sample fall below the specified limits, it is considered the "passed emission test" for that specific parameter. However, if the emissions exceed the set threshold, it is categorized as the "not passing emission test".

3 Results and Discussion

The CO emissions lambda trend in Fig. 3 illustrates the change in CO emissions with varying lambda values in each sample. Lambda values approaching 1 indicate ideal combustion conditions, while lambda values above or below 1 indicate inefficient combustion conditions [17]. Based on the data given, it can be observed that each sample shows a similar trend in reducing CO emissions with an increase in lambda values.

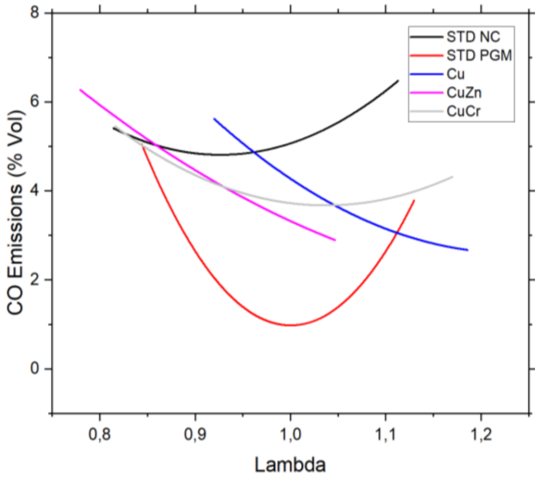

Fig. 3. Trend of CO emissions versus lambda.

According to Fig. 3, the term STD NC for non-catalyst standard, while STD PGM represents the standard that uses precious metal or platinum group metal catalytic converters. Furthermore, the terms Cu,CuZn, and CuCr refer to the use of alternative metal catalysts made of copper, brass, and chrome-plated copper respectively.

To determine the best catalytic converter, one can refer to the average and standard deviation values of CO emissions from all samples. The average CO emissions reflect the average level of emissions produced by each catalytic converter. Meanwhile, the standard deviation is used to depict the data variation around the average [18]. Thus, the lower the average and standard deviation values of CO emissions, the better and more consistent the performance of the catalytic converter in reducing CO emissions and converting them into CO_2[19] (Eq. 1 dan Fig. 4).

$$CO + ½O_2 \rightarrow CO_2 \qquad (1)$$

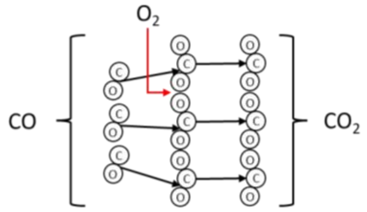

Fig. 4. Oxidation process of CO to CO_2 in the catalyst [20].

The average and standard deviation values of CO emissions were measured for each sample. The results show that the STD NC sample has an average CO emission of 5.19%Vol with a standard deviation of 1.92. The STD PGM sample has an average CO emission of 2.14%Vol with a standard deviation of 1.96. For the Cu sample, the average CO emission is 4.00%Vol with a standard deviation of 1.56. The CuZn sample exhibits an average CO emission of 4.78%Vol with a standard deviation of 1.62, while the CuCr sample has an average CO emission of 4.09%Vol with a standard deviation of 1.46.

Although the STD PGM sample has a lower average CO emission, the CuCr sample has a smaller standard deviation, indicating good consistency in CO emissions [21]. This suggests that although the average CO emission of the CuCr sample is slightly higher than that of the STD PGM sample, the CO emissions from CuCr tend to be more stable and well-controlled. The CuCr sample can be considered a viable alternative due to its comparable performance in reducing CO emissions and good emission consistency.

It should be noted that fluctuations in HC emissions can be influenced by the stoichiometric ratio of the fuel mixture [22]. When approaching a stoichiometric mixture (lambda around 1), HC emissions tend to be stable. However, when the vehicle deviates towards a lean fuel mixture(lambda less than 1), it leads to an increase in HC emissions [23]. Saxena et al. [24] revealed that the increased concentration of HC is generally caused by the incomplete combustion of rich or lean mixtures, which affects the combustion process efficiency and increases HC emissions. The process of oxidizing HC emissions into H_2O requires other substances such as O_2 to react [25] (Eq. 2 dan Fig. 5).

$$2HC + 2O_2 \rightarrow H_2O + 2CO_2 \qquad (2)$$

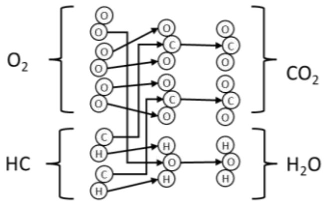

Fig. 5. Oxidation process of HC to $CO_2$and H_2O in the catalyst [26].

Based on Fig. 6, it can be observed that there is a tendency for higher HC emissions when the vehicle operates with a rich fuel mixture (lambda < 1). This can be seen in samples with lambda values below 1, such as the STD NC sample (0.945), which yielded HC emissions of 714 ppmVol. However, as the fuel mixture approaches stoichiometric (lambda around 1), HC emissions tend to decrease. This is evident in the STD PGM sample (0.975), which produced HC emissions of 308 ppmVol. On the other hand, when the vehicle deviates towards a lean fuel mixture (lambda > 1), HC emissions increase again, as seen in the STD NC sample (1.113) with HC emissions of 584 ppmVol.

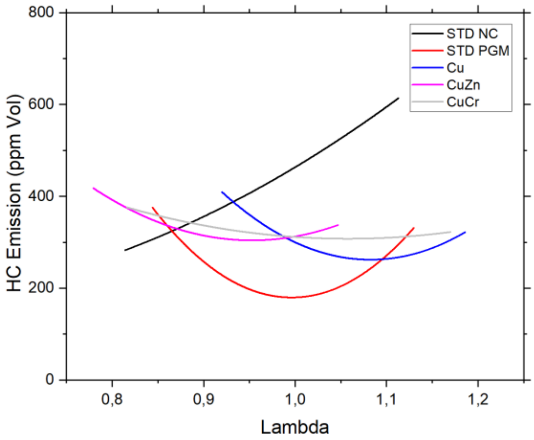

Fig. 6. Trend of HC emissions versus lambda.

The average and standard deviation values of HC emissions were measured for each sample. The results show that the STD NC sample has an average HC emission of 405 ppmVol with a standard deviation of 263. The STD PGM sample exhibits an average HC emission of 238 ppmVol with a standard deviation of 123. The Cu sample has an average HC emission of 317 ppmVol with a standard deviation of 108, while the CuZn sample shows an average HC emission of 353 ppmVol with a standard deviation of 119. The CuCr sample has an average HC emission of 320 ppmVol with a standard deviation of 106.

Based on the research findings, one sample that can be a competitor for the STD PGM sample (with an average HC emission of 238 ppmVol and a standard deviation of 123) is the CuCr sample. The CuCr sample exhibits an average HC emission of 320 ppmVol with a standard deviation of 106. Although the average HC emission is slightly higher than the STD PGM sample, the relatively low standard deviation indicates consistency in HC emissions.

The use of catalytic converters has a significant impact on reducing CO_2 emissions. As observed in the trend shown in Fig. 7, the average CO_2 emissions (11.53% Vol) in the STD PGM sample are slightly higher with a low standard deviation (1.50), indicating consistency in emission reduction. On the other hand, the CuCr sample exhibits low average CO_2 emissions (10.24) and smaller variation (1.46), demonstrating the effectiveness of using catalytic converters in significantly reducing CO_2 emissions. The lower the lambda value, the lower the concentration of CO_2 emissions. This indicates that the oxidation reaction of CO to CO_2 is proceeding well.

Ariyantoet al.[27] explain that the trend of CO_2 emissions related to lambda values in the context of stoichiometry indicates that CO_2 emissions tend to be low in rich mixtures, increase when approaching the ideal mixture, and decrease again in lean mixtures. Furthermore, Lee et al.[28] state that when lambda values are rich, there is an excess of fuel or insufficient air, which results in incomplete combustion and relatively low CO_2 emissions. On the other hand, in the scientific article by Warjuet al.[29] it is explained that when approaching the ideal mixture, combustion becomes more efficient and results in higher CO_2 emissions because the ideal amount of oxygen (O_2) is available.

However, in lean mixtures, although CO_2 emissions decrease due to more complete combustion, CO_2 emissions remain low because there is more oxygen (O_2) available to efficiently burn hydrocarbons.

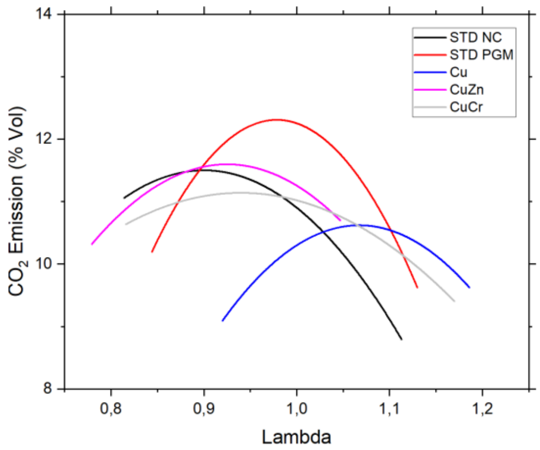

Fig. 7. Trend of CO_2 emissions versus lambda.

Referring to Fig. 8, it can be seen that the STD NC sample has an average O_2 value of 0.89% Vol, the STD PGM sample has an average O_2 value of 0.90% Vol, the Cu sample has an average O_2 value of 0.80% Vol, the CuZn sample has an average O_2 value of 1.10% Vol, and the CuCr sample has an average O_2 value of 0.95% Vol. Furthermore, the analysis of standard deviation indicates the level of O_2 variation, with the highest standard deviation found in the Cu sample with a value of 0.88, while the lowest standard deviation is found in the CuZn sample with a value of 0.82.

The larger the average O_2 value (the smaller the CO emissions) and the smaller the standard deviation of O_2, the better the quality. In this case, a sample that can be considered a competitor to STD PGM in terms of O_2 production is the CuZn sample. With an average O_2 value of 0.80% Vol, which is higher than STD PGM (0.90% Vol), and a standard deviation of O_2 of 0.82, which is smaller than STD PGM (0.92), the CuZn sample shows an improvement in the average value and a decrease in the level of O_2 variation. This is consistent with the O_2 trend presented in Fig. 8.

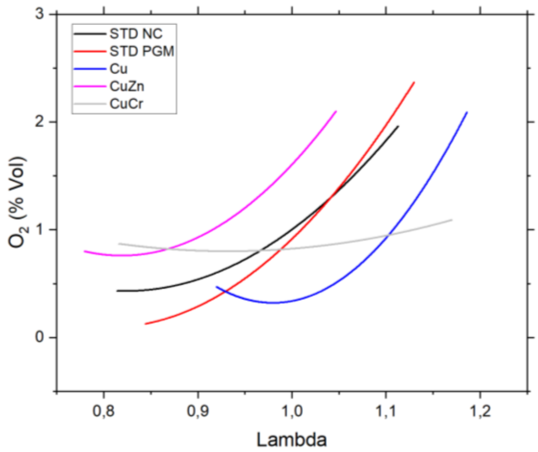

Fig. 8. Trend of O_2 versus lambda.

Based on the research results, the CuCr sample has proven to be effective and worthy of consideration as an alternative material for a catalytic converter. Although the average CO emissions from the STD PGM sample are lower, the CuCr sample shows good consistency in CO emissions. Additionally, while the average HC emissions from the CuCr sample are slightly higher, this sample still offers good emission consistency. However, to ensure the feasibility of each tested sample, a comparison with the standards set by the government should also be conducted.

These standards refer to the emission limits for category L motor vehicles (4-stroke motorcycles) established in the Minister of Environment Regulation No. 5 of 2006. The comparison results with these standards are presented in the Table 3.

Table 3. Comparison of emission test results to government standards

Emissions	RPM	Thresholds	Sample	Results	Category
CO	Idle	5.5 %Vol	STD NC	6.56 %Vol	Not passing emission test
			STD PGM	3.45 %Vol	Passing the emission test
			Cu	3.57 %Vol	Passing the emission test
			CuZn	4.18 %Vol	Passing the emission test
			CuCr	4.18 %Vol	Passing the emission test
HC	Idle	2400 ppmVol	STD NC	714 ppmVol	Passing the emission test
			STD PGM	326 ppmVol	Passing the emission test
			Cu	386 ppmVol	Passing the emission test
			CuZn	451 ppmVol	Passing the emission test
			CuCr	451 ppmVol	Passing the emission test

From the data presented in Table 3, it can be concluded that the use of catalytic converters is generally effective in reducing CO and HC emissions compared to the use of standard exhaust systems (STD NC). The test results show that the CO and HC emissions from all research samples are below the established threshold after the implementation of catalytic converters. This indicates that catalytic converters play a crucial role in reducing harmful emissions.

In observing the comparison of emission results in Table 3 with the emission standards established by the government, it becomes apparent that the CO emissions from the STD NC sample surpass the designated limit of 5.5% Vol. Therefore, the STD NC sample falls under the category of "not passing the emission test" for CO emissions. On the other hand, the CO emissions from the STD PGM, Cu, CuZn, and CuCr samples meet the established emission standards and are categorized as "passing the emission test" for CO emissions.

It is also omply with the government's HC emission standards, which are below the threshold of 2400 ppmVol. This indicates that the HC emissions from all samples fall under the category of "passing the emission test" for HC emissions. However, it should be noted that if any emission standard fails to meet the limits set by the government, the sample is categorized as "not passing the emission test". In this context, the STD NC sample does not meet one of the emission standards.

These results reinforce previous studies on the utilization of catalytic converters with alternative metal materials conducted by prior researchers. Furthermore, these findings underscore the significance of employing catalytic converters in mitigating harmful emissions and ensuring improved air quality. By adhering to government-set emission standards, vehicles can contribute to endeavors aimed at exhaust gas control, thereby positively impacting public health and environmental preservation.

In terms of comparative analysis, it is evident that several studies delve into the utilization of copper (Cu)-based catalysts in catalytic converters. The research by Shoffanet al.[1] reveals that the addition of copper-based catalytic converters with a circular tube model can reduce CO emissions by 16.67% and HC emissions by 32.54%. Similarly, the study by EllyanieandOktabri[9] investigates the influence of the number of brass (CuZn) catalyst plates on the performance of the Yamaha Jupiter MX engine. The results indicate that an increase in the number of copper catalyst plates enhances engine efficiency by 17.65%.

Conversely, the research by Irawan et al. [8] on the optimal design of manganese-coated copper (Cu) catalytic converters aims to reduce Carbon Monoxide (CO) emissions from gasoline exhausts. The outcomes demonstrate enhanced CO emission reduction through optimized catalyst materials. In the realm of advanced catalytic technology, the study by Warjuet al.[10] involves the application of copper (Cu) and chromium-coated catalysts in metal catalytic converters. The research showcases a significant decrease in CO and HC emissions from four-stroke gasoline engines with the utilization of Cu+Cr metal catalytic converters.

On a different note, the studies by Kim et al. and Prabhaharet al.explore the use of copper oxide (CuO) catalysts in distinct contexts. Kim et al.[30] report on a dual-bed catalytic system utilizing Ba/Al_2O_3 and Cu/Al_2O_3 catalysts to produce linear 1-octene from 1-octanol. Meanwhile, Prabhaharet al.[31] focus on implementing CuO_2 nanoparticle incorporation onto metal mesh surfaces to enhance heat transfer performance in catalytic converters and reduce exhaust emissions.

About environmental impact and public health, these research outcomes carry significant implications. Implementing effective catalytic converters in vehicles can aid in reducing hazardous gas emissions like CO and HC, contributing to improved air quality and public well-being. Ensuring vehicles adhere to governmental emission standards allows us to contribute to enhanced environmental protection efforts and minimize the adverse effects of air pollution.

4 Conclusion

Based on the emission measurements of various catalytic converter samples, it can be concluded that the CuCr sample demonstrates good performance in reducing CO and HC emissions. The CuCr sample exhibits an average CO emission of 4.09%Vol with a standard deviation of 1.46, indicating a strong consistency in CO emissions. Meanwhile, the average HC emission from the CuCr sample is 320 ppmVol with a standard deviation of 106, demonstrating consistent HC emissions.

Although the STD PGM sample has a lower average CO emission, the CuCr sample maintains good consistency in CO emissions with a smaller standard deviation. This positions the CuCr sample as a viable alternative with nearly comparable CO emission reduction performance and strong consistency. The general utilization of catalytic converters proves effective in reducing both CO and HC emissions, and all research samples comply with government HC emission standards. However, it should be noted that the STD NC sample exceeds the established CO emission threshold, categorizing it as a fail for CO emissions.

The implications of this research highlight the importance of using catalytic converters in reducing harmful emissions from vehicles. By complying with the emission standards set by the government, it is expected that the air environment will become cleaner, resulting in better air quality. The application of this research lies in the development of more effective catalytic converters for reducing CO, HC, and CO_2 emissions. Additionally, this research also demonstrates the potential of using alternative metal catalysts such as CuCr as viable alternatives to catalytic converters.

Future researchers can conduct further studies by considering other important factors that influence exhaust gas emissions, such as vehicle operational variables and the types of fuel used. Furthermore, research can expand the sample size and variation of catalytic converters to gain a more comprehensive understanding of their performance and effectiveness.

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