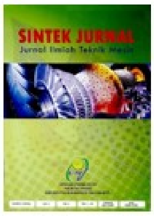
SINTEK JURNAL: Jurnal Ilmiah Teknik Mesin
ISSN: 2088-9038, e-ISSN: 2549-9645
Homepage: http://jurnal.umj.ac.id/index.php/sintek



CHARACTERIZATION OF CATALYTIC CONVERTER MADE FROM CHROME-PLATED COPPER PLATE CATALYST FOR GASOLINE MOTORS

RM. Bagus Irawan[1,*], Achmad Sholecan[2], M. Subri[1], Antonius Pantomy[1]

[1]Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Semarang, Semarang, Jawa Tengah, 50273, Indonesia
[2]Department of Electrical Engineering, Faculty of Engineering, Universitas Muhammadiyah Semarang, Semarang, Jawa Tengah, 50273, Indonesia

[*]E-mail: bagusirawanmail@yahoo.com

Accepted: 12-02-2024 Revised: 27-04-2024 Approved: 01-06-2024

ABSTRACT

This study characterizes copper (Cu) and chrome-plated copper (Cu-Cr) catalyst materials used in catalytic converters for gasoline engines. The objective is to investigate morphological and compositional changes resulting from exhaust gas emission testing. Scanning Electron Microscopy (SEM) coupled with Energy Dispersive X-ray Spectroscopy (EDX) was employed for microstructural analysis of the catalyst materials. The research examines morphological changes in Cu and Cu-Cr catalysts before and after exhaust gas emission testing, along with elemental composition alterations. Results indicate that exhaust gas exposure significantly alters the morphology and composition of both catalyst types. Morphologically, Cu catalyst particles originally flat with fine grains exhibited rougher, uneven surfaces with random grain formations and porosity post-testing. Similarly, Cu-Cr catalyst surfaces transformed from smooth to uneven, marked by darkened spots. Compositionally, Cu catalysts initially consisting of five elements (Cu 82.92%, O 5.96%, C 10.22%, Cl 0.60%, Si 0.29%) changed to include eight elements (Cu 70.65%, O 12.89%, C 12.85%, Cl 0.66%, Si 0.27%, N 1.74%, Al 0.27%, S 0.67%). Cu-Cr catalysts initially composed of three elements (Ni 87.65%, Cr 10.50%, C 1.85%) evolved to five elements (Ni 86.01%, Cr 6.56%, O 5.70%, O 1.42%, S 0.71%). These findings underscore the transformative effects of exhaust gas exposure on catalyst materials, influencing both their morphology and elemental composition, crucial for enhancing catalytic converter performance and durability in automotive applications.

Keywords: Catalytic Converter; Cu Catalyst; Cu-Cr Catalyst; SEM-EDX.

ABSTRAK

Penelitian ini mengkarakterisasi bahan katalis tembaga (Cu) dan tembaga berlapis krom (Cu-Cr) yang digunakan dalam konverter katalitik untuk mesin bensin. Tujuannya adalah untuk menyelidiki perubahan morfologi dan komposisi yang dihasilkan dari pengujian emisi gas buang. Scanning Electron Microscopy (SEM) yang digabungkan dengan Energy Dispersive X-ray Spectroscopy (EDX) digunakan untuk analisis mikrostruktur bahan katalis. Penelitian ini meneliti perubahan morfologi pada katalis Cu dan Cu-Cr sebelum dan sesudah pengujian emisi gas buang, serta perubahan komposisi unsur. Hasil penelitian menunjukkan bahwa paparan gas buang secara signifikan mengubah morfologi dan komposisi kedua jenis katalis. Secara morfologi, partikel katalis Cu yang awalnya datar dengan butiran halus menunjukkan permukaan yang lebih kasar dan tidak rata dengan formasi butiran acak dan porositas setelah pengujian. Demikian pula, permukaan katalis Cu-Cr berubah dari halus menjadi tidak rata, ditandai dengan bintik-bintik yang menggelap. Secara komposisi, katalis Cu yang awalnya terdiri dari lima unsur (Cu 82,92%, O 5,96%, C 10,22%, Cl 0,60%, Si 0,29%) berubah menjadi delapan unsur (Cu 70,65%, O 12,89%, C 12,85%, Cl 0,66%, Si 0,27%, N 1,74%, Al 0,27%, S 0,67%). Katalis Cu-Cr yang awalnya terdiri dari tiga elemen (Ni 87,65%, Cr 10,50%, C 1,85%) berevolusi menjadi lima elemen (Ni 86,01%, Cr 6,56%, O 5,70%, O 1,42%, S 0,71%). Temuan ini menggarisbawahi efek transformatif dari paparan gas buang pada bahan katalis, yang memengaruhi morfologi dan komposisi unsurnya, yang sangat penting untuk meningkatkan kinerja konverter katalitik dan daya tahan dalam aplikasi otomotif.

Kata Kunci: *Konverter Katalitik; Katalis Cu; Katalis Cu-Cr; SEM-EDX.*

1. Introduction

A catalytic converter is essential in mitigating the environmental impact of internal combustion engines by converting toxic exhaust gases into less harmful substances [1]. This device relies on catalyst materials to facilitate chemical reactions that convert pollutants like CO, HC, and NOx into CO2 and water vapor [1], [17]. Traditionally, catalytic converters utilize precious metals such as Palladium, Platinum, and Rhodium due to their high catalytic efficiency, capable of reducing emissions by 80-90% [6].

In addition to precious metals, alternative catalyst materials like Platinum, Nickel, Manganese, Chromium, and their oxides serve as effective oxidation catalysts [8], [9]. Metals such as iron, copper, nickel alloys, and their oxides function as reduction catalysts [8], [9]. The effectiveness of these materials varies, with Pt, Pd, Ru > Mn, Cu > Ni > Fe > Cr > Zn ranking from highest to lowest in catalytic performance [2].

Recently, chrome-plated copper has gained attention as a substitute catalyst material for expensive precious metals in gasoline engine catalytic converters. Previous studies have explored copper and manganese-coated copper catalysts, adjusting catalyst cell configurations to optimize CO emission reduction across varying engine speeds [3], [4], [8], [14].

Despite extensive research on catalyst materials and their effects on emissions reduction, little attention has been given to the morphological and compositional changes these materials undergo following exhaust gas exposure. Understanding these changes is crucial for improving catalytic converter performance and durability.

Therefore, this study focuses on characterizing copper (Cu) and chrome-plated copper (Cu-Cr) catalysts before and after exposure to exhaust gas emissions. The research aims to analyze morphological alterations and compositional shifts induced by exhaust gas conditions. Material characterization utilizes Scanning Electron Microscopy coupled with Energy Dispersive X-ray Spectroscopy (SEM-EDX) to examine catalyst microstructures and elemental compositions [11], [12], [15], [16], [17], [18], [19].

This research contributes to the understanding of how chrome-plated copper catalysts perform under real-world conditions, offering insights into their potential as cost-effective alternatives in automotive emissions control.

The research has been modified by using a different catalyst material, namely copper (Cu) coated with chrome (Cr). The objectives of the research are (i). researchers conducted studies related to the morphological changes in copper catalyst materials (Cu) and copper chrome catalysts (Cu-Cr) before and after exhaust gas emission test treatment, and (ii). Researchers conducted a study regarding changes in the composition (elements) of copper (Cu) catalyst materials and copper chrome (Cu-Cr) catalysts before and after exhaust gas emission test treatment.

2. Methods

The catalytic converter used in the research is a copper plate (Cu) and chrome-plated copper (Cu-Cr) catalyst material as shown in Figure 1.

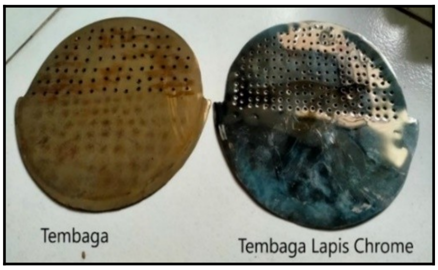


Figure 1. Copper Catalyst Plate and Chrome Plated Copper Catalyst Plate.

Before testing samples, researchers prepare test specimens. As for the test specimens for copper catalyst material (Cu) and chrome-plated copper catalyst material (Cu-Cr), the researchers cut them to a smaller size, namely 1 cm x 1 cm so that they could be installed in the SEM-EDX machine holder.

The catalyst material specimens in the study consisted of 4 pieces, namely copper (Cu) catalyst test specimens (before emission test), copper (Cu) catalyst specimens (after emission test), chrome-plated copper (Cu-Cr) catalyst test specimens (before test emissions), and chrome-plated copper (Cu-Cr) catalyst specimens (after emission tests). The catalyst material test specimen is shown in Figure 2, as follows:

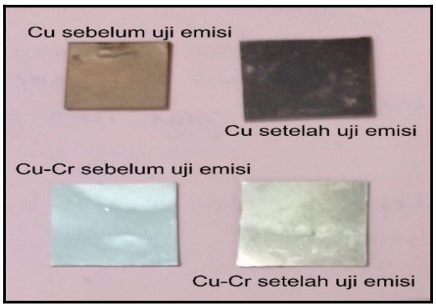


Figure 2. Specimen of Catalyst Material Before Emission Test and After Emission Test.

The testing machine used to characterize copper (Cu) and chrome-plated copper (Cu-Cr) catalyst materials is

SEM-EDX. The testing machine is a combination of two types of instruments, namely SEM and EDX.

Scanning Electron Microscope (SEM) is an instrument that functions to determine the morphology or surface structure of a solid sample through an image. Meanwhile, Energy Dispersive X-Ray (EDX) is an instrument that functions to analyze the chemical elements or characteristics of a material.

Thus, testing using SEM-EDX can be used to analyze the shape and morphology of the surface and to determine the composition of a substance or materials from the test specimen. The SEM-EDX testing machine used in the research is shown in Figure 3, as follows:

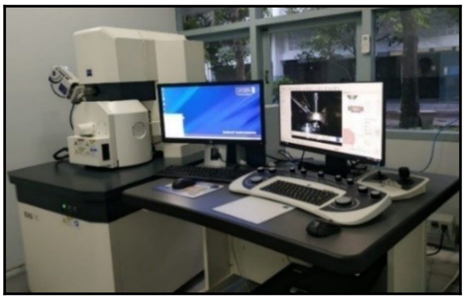


Figure 3. SEM-EDX Test Machine

Table 1. SEM-EDX Test Machine Specifications

No	Specifications	Description
1	Brand	Zeiss
2	Type	EVO 10
3	Resolution	High Vacuum : ±3nm at 30kV, ± 8 nm at 3 V
4	Accelerating Voltage	Min range approx. 200V to 30KV
5	Magnification	Low: less than 7x High: more than 1.000.000x
6	Electro Gun	Tungsten heated cathode
7	Objective Lens	Super conical lens
8	Objective Lens Hole	Three positions controllable in the X/Y direction

SEM-EDX testing was carried out at the ATMI Surakarta Polytechnic Laboratory. The SEM test was carried out to determine the structural changes contained in the specimen before the emission test and after the emission test. Surface morphology results of catalyst material test specimens using 5000 x and 10,000 x magnification. Meanwhile, EDX is used to analyze the chemical elements or characteristics of test specimens.

The test specimen size (1 cm x 1 cm) in the study will be installed in the SEM-EDX machine testing holder. After being installed in the holder, the test specimen is inserted into the SEM-EDX machine for testing and observation via computer. The place for installing the test specimen in the holder and placing the test specimen on the SEM-EDX machine can be seen in Figure 4 and Figure 5, as follows:

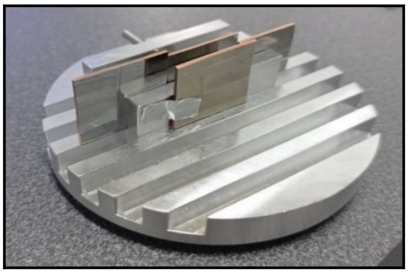


Figure 4. Place of Installation of Test Specimens on the SEM-EDX Test Machine Holder

Figure 5. Placement of Specimens on the Testing Machine (SEM-EDX)

3. Results and Discussion

3.1. Test Results Using SEM

SEM testing on catalyst materials aims to determine changes in the characteristics of copper (Cu) and chrome-plated copper (Cu-Cr) catalyst materials before and after exhaust gas emission testing treatment.

Morphology Testing of Cu Catalyst Material Before Emission Test.

The first test was carried out on the copper (Cu) catalyst material test specimen in conditions before exhaust gas emission test treatment. The test results with a magnification of 5000 x are shown in Figure 6, as follows:

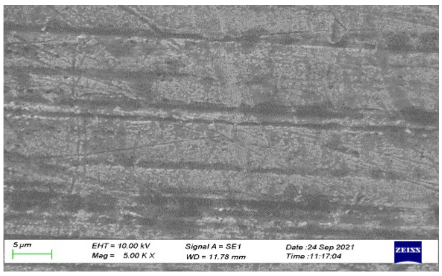


Figure 6. Morphology of Cu Catalyst Material Before Emission Test Treatment

The results of SEM testing which has been carried out on test specimens of copper catalyst material before the exhaust gas emission testing treatment is shown in Figure 6. The test results with a magnification of 5000 times the particle size in a 5 µm copper plate show that the morphology of the material shows the shape and size of the Cu particles are flat. with fairly fine grain.

Morphology Testing of Cu Catalyst Material After Emission Test

The next test is testing the copper (Cu) catalyst material test specimen under conditions after exhaust gas emission test treatment. The results of the test by magnifying 5000 times can be seen in Figure 7, as follows:

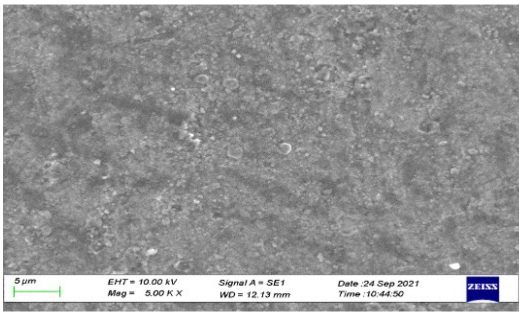


Figure 7. Morphology of The Cu Catalyst Material After Emission Test Treatment

Figure 7 shows the results of SEM testing with a magnification of 5000 times with a particle size in a copper plate of 5 µm. From the test results, it can be seen that the morphology of the catalyst material has changed. The surface of the catalyst material tends to be rougher (uneven), there are randomly shaped grains on several sides, and it looks like it has cavities (porous). The change occurred due to the emission test treatment factor. The change occurs because the exhaust gas that passes through the catalyst material has heat or a hot temperature.

Morphology Testing of Cu-Cr Catalyst Material Before Emission Test

Figure 8 shows a test specimen of chrome-plated copper (Cu-Cr) with a magnification of 5000 times the particle size in a 5 µm chrome-plated copper plate. The test results show that the morphology of the chrome-plated copper catalyst material is flatter and smoother than the copper catalyst. The difference is caused by the chrome plating process which covers the entire copper surface.

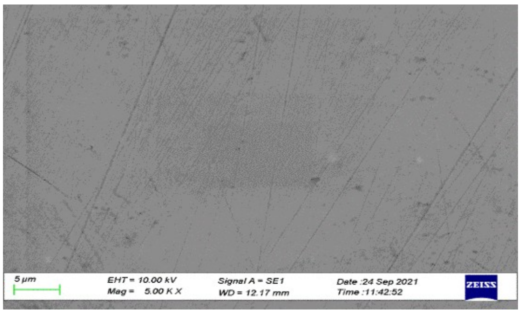


Figure 8. Morphology of Cu-Cr calatic material before emission test treatment

Morphology Testing of Cu-Cr Catalyst Material After Emission Test.

Figure 9 shows the morphology of the chrome-plated copper (Cu-Cr) catalyst material after emission test treatment. The test was observed using SEM with a magnification of 5000 times the particle size on a 5 µm chrome-plated copper plate. Figure 9 shows that the surface which originally looked smooth, now has spots and looks darker. The change occurred due to factors resulting from the emission test treatment. The change is due to exhaust gas passing through the catalyst material and having heat or a hot temperature.

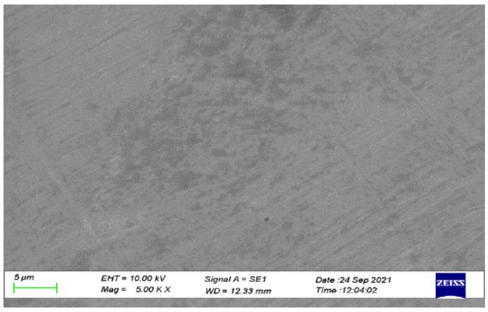


Figure 9. Morphology of Cu-Cr Calatic Material After Emission Test Treatment

3.2. Material Composition Test Using EDX

Testing Cu Catalyst Material Composition Before Emission Test

The results of testing the composition of the Cu catalyst material before the emission test treatment are shown in Figure 10. The figure shows a graph of the composition of five elements, namely Cu, O, C, Cl, and Si. The Cu element looks very dominant in the composition graph Figure 10.

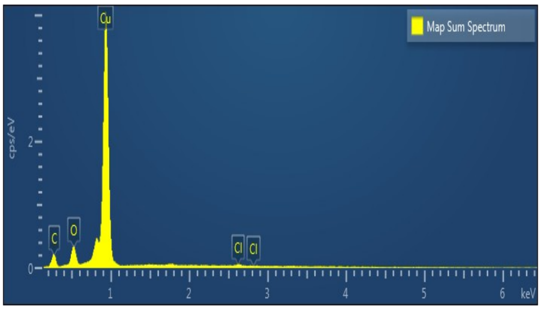


Figure 10. Graph of The Composition of The Cu Catalyst Material Before The Emission Test Treatment

Table 2. Composition of Cu Catalyst Material Before Emission Test

Element	Line Type	Weigh %	Weigh % sigma	Atomic %
Cu	L Series	82.92	0.45	51.05
O	K Series	5.96	0.20	14.58
C	K Series	10.22	0.41	33.29
Cl	K Series	0.60	0.11	0.67
Si	K Series	0.29	0.09	0.41
Total		100		100

From Table 2 it can be seen that the dominant catalyst material composition is Cu with a mass of 89.92%.

Testing Cu Catalyst Material Composition After Emission Test

The results of testing the composition of the Cu catalyst material after the emission test treatment are shown in Figure 11. The graphic image shows that there are five elements consisting of Cu, O, C, Si, and Cl and three new elements N, Al, and S appear. The Cu element is still visible in the image. still very dominant.

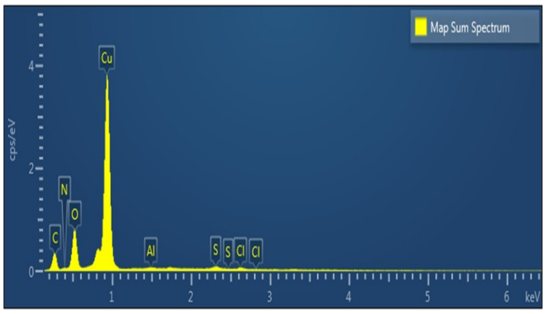


Figure 11. Graph of The Composition of The Cu Catalyst Material After The Emission Test Treatment

Table 3 shows the composition of the catalyst material which is still dominated by the Cu element, which originally had a mass of 89.92%, down to 70.65%. Apart from that, there is a new element S with a mass of 0.76%, element N with a mass of 1.74%, and element Al with a mass of 0.27%. Changes in material composition and the presence of new elements in the catalyst material are caused by the exhaust gas emission test treatment. The change is due to the heat factor in the catalytic converter chamber or the hot temperature of the exhaust gas passing through the Cu catalyst plate.

Table 3. Composition of Cu Catalyst Material After Emission Test

Element	Line Type	Weigh %	Weigh % sigma	Atomic %
C	K Series	12.85	0.37	33.73
O	K Series	12.89	0.22	25.41
Cu	L Series	70.65	0.43	35.07
S	K Series	0.67	0.09	0.66
Cl	K Series	0.66	0.09	0.59
N	K Series	1.74	0.28	3.92
Si	K Series	0.27	0.07	0.30
Al	K Series	0.27	0.07	0.32
Total		100		100

Testing the Composition of Cu-Cr Catalyst Materials Before Emission Tests

The results of testing the composition of the Cu-Cr catalyst material before the emission test treatment are shown in Figure 11. The graphic image shows that there are three elements consisting of Ni, Cr, and C. The Ni element looks very dominant.

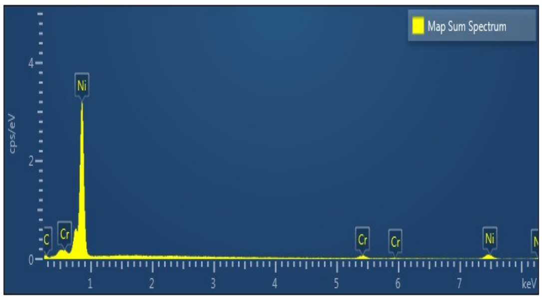


Figure 12. Graph of The Composition of The Cu-Cr Catalyst Material After Emission Test Treatment

Table 4. Composition of Cu-Cr Catalyst Material Before Emission Test

Element	Line Type	Weigh %	Weigh % sigma	Atomic %
Ni	L Series	87.65	1.66	80.74
Cr	L Series	10.50	1.68	10.52
C	K Series	1.85	0.27	8.33
Total		100		100

Table 4 shows that the dominant Cu-Cr catalyst material composition is Ni with a mass of 87.65%. The loss of copper elements in the Cu-Cr catalyst is caused by the chrome electroplating process on the copper plate. In the chrome electroplating process, it is first coated with a layer of nickel. The causes the entire surface of the copper plate to be covered with a layer of nickel and a layer of chrome as the final layer.

Testing the Composition of Cu-Cr Catalyst Material After Emission Test

The results of testing the composition of the Cu-Cr catalyst material after the emission test treatment are shown in Figure 13. From the graphic image, you can see the composition of five elements consisting of Ni, Cr, and C. O and S. The Ni element still looks more dominant.

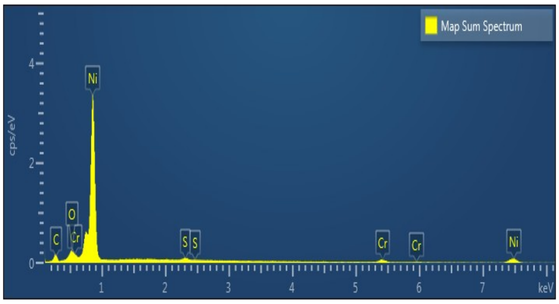


Figure 13. Graph of The Composition of The Cu-Cr Catalyst Material After Emission Test Treatment

Table 5. Composition of Cu-Cr Catalyst Materials After Emission Test

Element	Line Type	Weigh %	Weigh % sigma	Atomic %
Ni	L Series	86.01	1.36	68.35
Cr	L Series	6.56	1.44	5..89
C	K Series	5.70	0.26	20.57
0	K Series	1.42	0.14	4.15
S	K Series	0.71	0.09	1.03
Total		100		100

From Table 5 it can be seen that the dominant Cu-Cr catalyst material composition is still Ni even though the mass has decreased from 87.65% to 86.01%. Apart from that, a new element O had a mass of 1.42%, and the element S had a mass of 0.71%.

The same conditions were carried out in the treatment before the emission test. For treatment after the Cu-Cr catalyst emission test, the copper catalyst element in the Cu-Cr catalyst is lost. This is caused by the chrome electroplating process on the copper plate. In the chrome electroplating process, it is first coated with a layer of nickel. The causes the entire surface of the copper plate to be covered with a layer of nickel and a layer of chrome as the final layer.

Changes in material composition and the emergence of new elements in the catalyst material are caused by the exhaust gas emission test treatment. This change is caused by the heat factor in the Catalytic Converter chamber or the hot temperature of the exhaust gas passing through the Cu-Cr catalyst plate.

4. Conclusion

The exhaust gas emission tests conducted on the catalytic converters revealed significant changes in the morphology and material composition of both the Cu and Cu-Cr catalysts. These changes were primarily attributed to the high temperatures of the exhaust gases passing through the catalytic material. Specifically, the Cu catalyst, which initially exhibited flat particles with fine grains, developed a rougher and more uneven surface with randomly shaped grains, cavities, and porosity. Similarly, the Cu-Cr catalyst's originally smooth surface became uneven and spotted, with some areas appearing darker.

In terms of material composition, the Cu catalyst initially comprised five elements: Cu (82.92%), O (5.96%), C (10.22%), Cl (0.60%), and Si (0.29%). After the emission tests, the composition changed to include eight elements: Cu (70.65%), O (12.89%), C (12.85%), Cl (0.66%), Si (0.27%), N (1.74%), Al (0.27%), and S (0.67%). The Cu-Cr catalyst also experienced compositional changes, initially consisting of Ni (87.65%), Cr (10.50%), and C (1.85%), and later transforming to include Ni (86.01%), Cr (6.56%), O (5.70%), and new elements O (1.42%) and S (0.71%). These findings highlight the impact of exhaust gas exposure on the structural and compositional integrity of catalyst materials, underscoring the need for continued research into optimizing catalyst formulations for enhanced performance and durability in automotive applications.

Future research should focus on modifying catalyst materials to enhance their performance and durability. Additionally, it is essential to investigate the effects of morphological changes and compositional alterations on the lifespan and effectiveness of catalysts in reducing exhaust gas emissions. This will provide a deeper understanding of how these factors influence catalytic efficiency and contribute to the development of more robust and effective catalytic converters for automotive applications.

References

[1] Catalyst Handbook. Wolfe Scientific Book, London - England, Springer - Verlag New York Inc, 1970.

[2] Dowden et al, "Catalytic Handbook," Verlag New York, Inc, 1970.

[3] B. Irawan, "Rancang Bangun Catalytric Converter dengan Material Substrat Tembaga (Cu) untuk Mereduksi Emisi Gas CO," J. Traksi, 2004.

[4] Warju, "Pengaruh Penggunaan catalytic Converter Tembaga berlapis Mangan Terhadap Kadar Polutan

Motor Bensin Empat langkah," Institut Teknologi Surabaya, 2006.
[5] Obert, Internal Combustion Engine and Air Pollution, 3rd ed. Harper & Row, Publisher, Inc., New York, 1973.
[6] Liyod, Handbook of Industrial Catalysts, Fundamental and Applied Catalysis, 2011.
[7] Mattey, "Dennis Dowden and the Development of Catalytic Science," Technology Review. [Online]. Available: www.technology.mattey.com, 2014.
[8] B. Irawan, "Pengaruh Letak Pemasangan Catalytic Converter Terhadap Keluaran Emisi Gas Carbon Monoksida dan Hidro Carbon Motor Bensin," Maj. Ilm. Tek. Mesin, Traksi, 2007.
[9] H. Heisler, Advanced Engine Tecnology, Hodder Headline Group, London, 1995.
[10] J. B. Heywood, Internal Combustion Engine Fundamentals, International ed. Graw-Hill, Inc., New York, 1988.
[11] B. Irawan, "Karakterisasi Katalis Tembaga Pada Catalytic Converter Untuk Mengurangi Emisi Gas Carbon Monoksida Motor Bensin," Maj. Ilm. Tek. Mesin, Traksi, 2014.
[12] B. Irawan, "Karakterisasi Catalytic Converter Motor Bensin Berbahan Katalis Tembaga Lapis Mangan," Sem. Nas. Tek. Kimia Undip, 2016.
[13] B. Irawan, "Pengaruh Perubahan Putaran Mesin Terhadap Temperatur Catalytic Converter Berbahan Logam Transisi Tembaga Mangan," Sitek J., 2021.
[14] B. Irawan, "Effect Of Number Of Transition Metal Catalyst Cell Manganese Catalytic Converter On Exhaust Basis Emission Output Carbon Monoxide Motor Gasoline," Sintek J., 2022.
[15] H. Abdullah, "Pembuatan dan Karakterisasi serta Aplikasi Katalik Konverter untuk Filter Gas Buang Kenderaan Bermotor Berbahan Bakar Premium," J. USU, 2012.
[16] M. L. Marlisa, "Uji Karakteristik Nanopartikel Magnetit (Fe3o4) Menggunakan X-Ray Diffraction Dan SEM," 2017. [Online]. Available: http://repositori.uin-alauddin.ac.id/9216/1/
[17] H. Singh, "Performance Analysis Of Catalytic Converter," J. Emerg. Technol. Innov. Res., 2018.
[18] K. D. P., "Design And Development Of Automotive Catalytic Converter Using Non-Nobel Catalyst For The Reduction Of Exhaust Emission: A Review," 2022. [Online]. Available: https://doi.org/10.1016/j.matpr.2022.03.350
[19] K. S. L. Kuen, "Fine Structural Characterization Of Noble Metals In Washcoat Of Motorcycle Three-Way Converter Catalysts," J. Environ. Chem. Eng., 2023. [Online]. Available: https://www.sciencedirect.com/journal/journal-of-environmental-chemical-engineering