Research Article

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Study of Emission Characteristics on a CI Engine Using a Cost-effective Cu-Zn-coated Catalytic Converter

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ABSTRACT

Emissions from automobile exhaust gases contribute to a major part of air pollution. Daily, the usage of the automobile increases to fulfill human comfort. In general, automobile engine exhaust emission is a major contributor to air pollution in India. Carbon monoxide (CO), oxides of nitrogen (NO_x) and hydrocarbons (HCs) are major exhaust emission components that are frequently examined in emission studies. High concentration of these emissions in the atmosphere affects human health. To overcome this problem, many researchers are working on alternative methods like fuel blends, piston-cylinder coating and exhaust treatment processes. The three-way catalytic converter is used in automobile engines to reduce HCs, CO and NO_x emissions using rare and expensive materials like palladium, platinum and rhodium. In this research work, a 3.7kW single-cylinder 4-stroke diesel engine running at 1500rpm was chosen to study emission characteristics, using a Cu-Zn-coated catalytic converter, for various engine load conditions. At full load conditions, the catalytic converter effectively reduced the emissions of hydrocarbons, carbon monoxide and oxides of nitrogen by 72%, 60% and 65%, respectively, compared with conventional CI engines without catalytic converters.

Keywords: Copper; Zinc; Catalytic converter; Emission.

1. INTRODUCTION

Air pollution from mobile sources such as automobiles contributes to substantial air quality problems in developed and developing countries (Khalasane, 2016). Air pollution causes quite serious health problems. Air pollution increases the risk of serious disorders like damaged lungs. It increases the occurrence of respiratory ailments such as bronchitis and asthma, causing a substantial financial load on our healthcare system (Naveenkumar *et al.* 2020). According to the Environmental Protection Agency (EPA), motor vehicle exhaust may account for up to 95% of all city CO emissions. A typical passenger vehicle emits roughly 4.6 metric tonnes of CO_2 each year.

Several harmful air pollutants have been detected in diesel exhaust gas (Vembathu *et al.* 2020). Incomplete combustion of the fuel results in emissions such as carbon monoxide (CO), oxides of nitrogen (NO_x), volatile organic compounds (VOC), hydrocarbons (HCs), aromatics and oxygenated species (Chirag and Rathod, 2012). The fuel consumption, fuel efficiency and annual mileage of a vehicle can all affect the emission levels. Researchers are experimenting with other strategies to manage this problem, such as changing the combustion and post-treatment processes (Venkatesan *et al.* 2017). Various cutting-edge technologies based on oxidation and three-way catalysts, adsorption, storage and filtration processes have recently been used in automobile exhaust after-treatment procedures to control emissions (Leman *et al.* 2017). The best option for reducing vehicle exhaust emissions among the available technologies has been discovered to be the catalytic converter. To reduce the quantity of pollution that leaves the tailpipe, catalytic converters are a crucial part of an automobile's emissions control system (Fernandes *et al.* 2002). Regardless of their origin, these oscillations considerably impact output emissions due to the catalyst's transient response to them. An ideal engine management system would have a model for this type of behavior so that adjustments could be made before problems reached the tailpipe.

As the combustion reactants from a diesel engine come into contact with the catalytic converter surface, they are transformed into harmless components (Khalasane, 2016). Due to their high reactivity, nobel materials such as platinum, palladium and rhodium-coated catalytic converters control exhaust emission levels (Aditya and Prajekta, 2017). On the other hand, these materials are hard to come by and expensive (Prashant, 2016). Researchers from academia and industry are developing low-cost, effective catalytic converters using alternative coating materials to address these issues.A catalytic converter may also transform dangerous pollutants like CO, HCs and NO_x into safe gases like carbon dioxide (CO_2), water vapor (H_2O), and nitrogen (N_2) through chemical processes (Chafidz *et al.* 2018).

Carbon monoxide is a by-product of the partial burning of fuel. It always exists during incomplete combustion and relies on the engine's applied air/fuel ratio. Hydrocarbons in the exhaust can be generated through several pathways (Dey and Chandra, 2020). On the other hand, high oxygen concentrations following combustion and high in-cylinder temperatures lead to the formation of nitrogen oxide emissions. Here, the substrate is made of the monolith, which results in an even distribution of exhaust fumes across the whole surface. This reduces pollutants due to this experimental work and furthers our compliance with Euro and Bharat standards (Naveenkumar *et al.* 2020). In Udhayakumar N et al. research, Ag and Zn were used as the catalysts in the catalytic converter. In his other work, V and Zn were used as a catalyst in a catalytic converter to control HC, CO and NO_x emissions upto 70, 50 and 70%, respectively (Udhayakumar *et al.* 2021). From the results in both studies, zinc acted as a good oxy-reduction agent to control NO_x emission from the tailpipe (Udhayakumar *et al.* 2021). A catalytic converter speeds up the oxidation of HC and CO pollutants and lowers NO_x. Regarding CO oxidation, its role is more fundamental due to the stronger metal-oxygen connection. The different metal-oxygen connections at the surface planes determine the surface structures. Selective partial oxidation reactions depend heavily on the true metal-oxygen stoichiometry and defect structure. The characteristics of catalysts are better understood from the structure and chemical sensitivity of CO oxidation processes. The surface energy of compounds is affected by the surface structures of transition metals, affecting their chemical characteristics (Dey and Chandra, 2020). The current research employed a catalytic converter with zinc and copper to examine emissions from a standard CI engine.

2. EXPERIMENTAL PROCEDURE

The honeycomb-structured membrane was separated from the catalytic converter to clean carbon and deposited using compressed air. The sulfuric acid (H_2SO_4) was used to remove carbon particles in the existing coating. This acid removes coated materials like palladium, platinum and rhodium from the membrane. Since noble materials are expensive, many researchers are working on alternative materials. In this work, copper and zinc were used as catalysts for oxidation and reduction processes, respectively. The coating process used aluminum oxide as a wash coat material. The membrane was kept inside the aluminum oxide solution during the coating process in the electrolysis setup. This process was continued for 1 hour and allowed for drying in a hot oven for 2 hours at 200 °C. In the next stage, the copper coating was done using copper nitrate and water solution. This consists of 27 g of copper nitrate in 1 litre of water. The membrane was immersed in copper nitrate solution and kept inside the ultraviolet setup for coating. An aerator in this setup ensures proper solution flow over the membrane during the coating process. This process was continued for 3 to 4 hours. After the coating process, the membrane was kept in a hot oven at 200 °C for 1 hour, for drying. The reddish brown on the membrane after the drying process ensures the presence of copper coating. The same procedures werefollowed for zinc coating with 29 g of zinc sulfate. The white color on the membrane after the drying process ensures the presence of zinc coating. Cu-Zn-coated catalytic converter preparation is shown in Fig. 1.

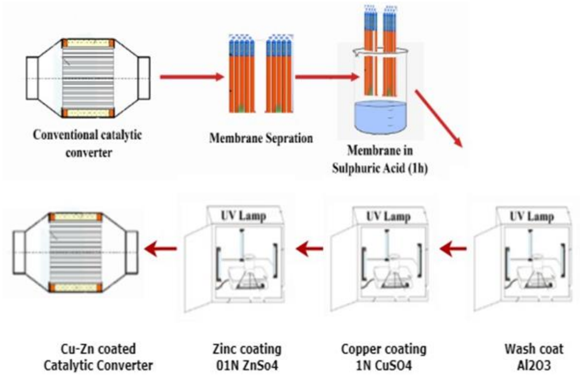
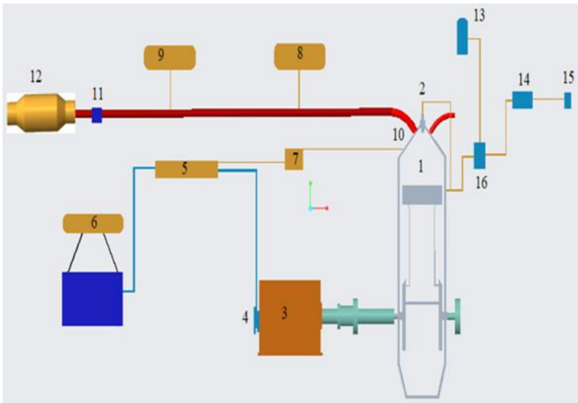


Fig. 1: Preparation of Cu-Zn-coated catalytic converter



1. Kirloskar TFV1 Engine
2. Injector
3. Eddy current dynamometer
4. TDC encoder
5. Indimeter
6. Fuel tank
7. Charge amplifier
8. AVL Di-gas analyzer
9. AVL smoke meter
10. Pressure transducer
11. Exhaust silencer
12. Cu-Zn Catalytic Converter
13. Fuel tank
14. Air Tank
15. Air Filter
16. Fuel Filter

Fig. 2: Experimental setup

2.1 Experiment setup

The copper and zinc-coated catalytic converter is attached to a 3.7 kW CI engine for emission studies. The results were compared with that of the diesel engines without catalytic converters. The experimental test rig of this test is shown in Fig. 2.

2.2 Catalytic Converter Design

The basic calculations used for catalytic converter chamber design using engine specification data are shown in Table 1.

Table 1. Test engine specifications

Description	Specifications
Engine make	Kirloskar
Bore and Stroke	87.5 mm and 110mm
Max. power	3.7 kW 1500 rpm
CR	17.5:1
Nozzle opening pressure	250 barat23° before TDC

For single cylinder,

$$\text{Volume flow rate} = \text{No. of intake strokes} \times \text{Swept volume}$$

$$= \frac{\pi}{4} \times d^2 \times L \times \left(\frac{N}{2}\right) \times 60$$

$$= 0.785 \times (0.087)^2 \times 0.11 \times \left(\frac{1500}{2}\right) \times 60$$

$$= 29.5 \frac{m^3}{h}$$

Space velocity=25,000 h^{-1}

$$\text{Catalyst volume} = \frac{VolumeFlowRate}{SpaceVelocity} == \left(\frac{29.5}{25,000}\right)$$

$$= 0.00118 m^3$$

Shell Dimensions:

For L = 2D

Volume = Area x Length

0.00118 = π/4 x D^2 x 2D

0.00236 = 3.14 x D^3

D^3 = (0.00236/3.14)

D^3 = 7.51 x 10^{-4} = 0.09 m

D=90 mm

L=2D = 2 x 0.090 m = 0.18 m = 108 mm

The catalytic converter and housing consisting of a honey comb core from inside were designed in CAD software and shown in Fig. 3 using the model calculation results.

3. RESULTS AND DISCUSSION

A conventional CI engine with an energy capacity of 3.5 kW was used to study the emission characteristics of diesel with a Cu-Zn-coated catalytic converter. The results were compared with the conventional engine without a catalytic converter. AVL 444L five-gas apparatus was used for the emission test.

3.1. Carbon Monoxide Emission

A study of emission characteristics was carried out on the CI engine to measure and compare exhaust gases at various load conditions using zinc and copper-coated catalytic converters. The CO emission is normally formed during and after the combustion process due to lower O_2 concentration and in-cylinder temperature for the oxidation process. CO emission variation with brake power is depicted in Fig.4. They refer to conventional engines for all engine load operations. Copper acts as a good oxidizing agent in the catalytic converter to enhance the oxidation reaction.

$$CO + 1/2\ O_2 \rightarrow CO_2 \quad (1)$$

The carbon monoxide eared to without catalytic converter operation. The carbon monoxide gas emission is minimized by 72% at full load conditions. The same appreciable result was noted in several research studies.

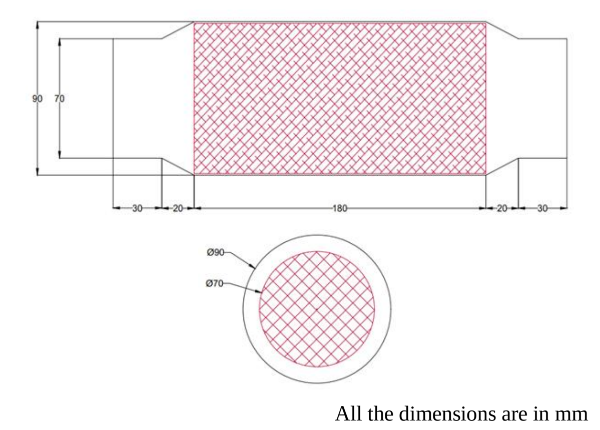


Fig. 3: Catalytic converter design

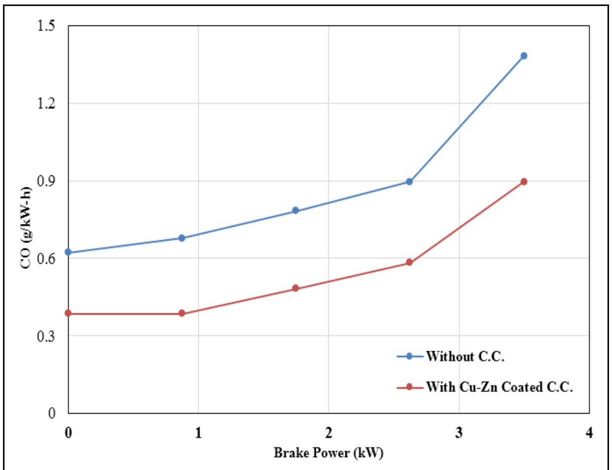


Fig. 4: Variation of CO emission with engine brake power

3.2 Hydrocarbon Emission

The lower in-cylinder temperature and oxygen concentration of the intake air leads to improper combustion resulting in UBHC emissions at the exhaust. A high concentration of UBHC may cause respiratory damage in humans. UBHC emission variation with brake power is shown in Fig. 5. The hydrocarbon emission levels are lower with a copper and zinc coated catalytic converter than with a conventional engine without a catalytic converter; this is due to the fact that copper in the membrane acts as a good oxidizing catalyst to enhance the oxidation reaction. Copper is an effective oxidation reaction that can accelerate the process of converting hydrocarbons into carbon dioxide and water vapour. Several research works arrived the same result.

$$2C_xH_Y + ½ (4X + Y) O_2 \rightarrow 2XCO_2 + YH_2O \quad (2)$$

$$C_xH_Y + 2O_2 \rightarrow H_2O + CO_2 \quad (3)$$

The hydrocarbon gas emission is minimized by 60% at full load conditions.

3.3 Oxides of Nitrogen

Oxides of nitrogen emissions are formed in the combustion chamber as a result of the excess O_2 level after combustion and the high in-cylinder temperatures. NO_x emissions can impact the respiratory system of humans at high levels. NO_x emission variation with brake power is shown in Fig. 6. The oxides of nitrogen emission levels are lower with copper and zinc membranes than with conventional engines at all load conditions. In all full load conditions, the engine produces 65% lower NO_x emission with a Cu-Zn catalytic converter compound than a conventional engine due to the presence of zinc which acts as a good oxi-reduction agent in the membrane to enhance the oxidation reaction. Nitrogen oxide can be changed into nitrogen and oxygen by lowered oxidation process from the engine exhaust.

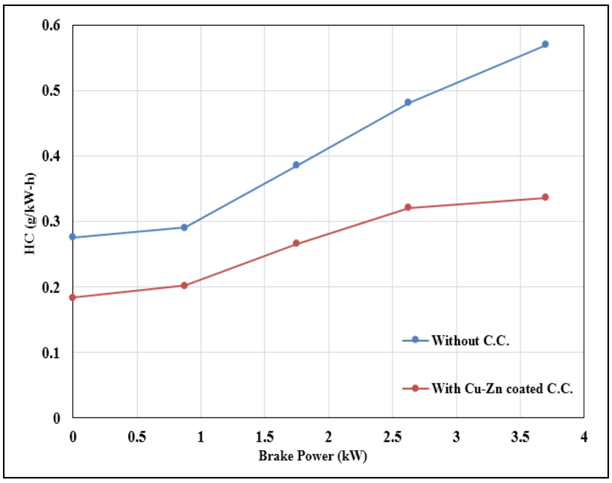


Fig. 5: HC variation with engine brake power

$$2CO + 2NO \rightarrow 2CO_2 + N_2 \quad (4)$$

$$CxHx + NO \rightarrow XCO_2 + 2H_2O + N_2 \quad (5)$$

3.4 Cost Analysis

The cost of after-treatment processes in automobiles and industries is notably high to comply with government regulations for a low-pollution environment. The noble metal-coated catalytic converter, containing platinum, palladium, and rhodium, is priced at approximately INR 35,000, contrasting with the cost of a modified catalytic converter. The modified version is 35% cheaper than the standard variant due to the utilization of cost-efficient metals like copper and zinc. In the Indian market context, the production cost of the proposed catalytic converter, encompassing materials and labor, amounts to around INR 19,500. This study underscores the effectiveness of the redesigned catalytic converter, even when considering manufacturing expenses.

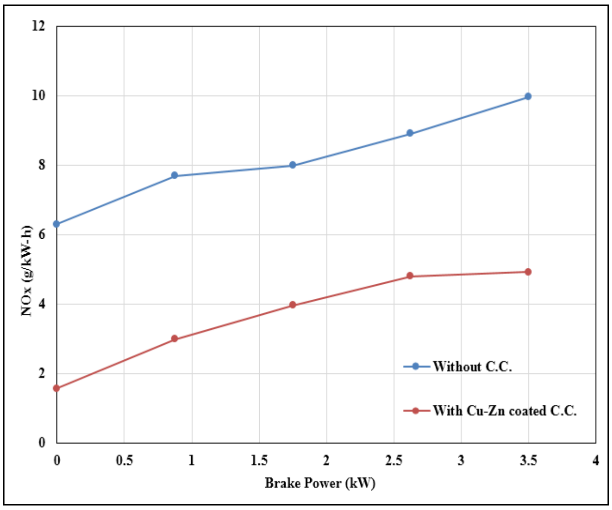


Fig. 6: NO_x emission variation with engine brake power

4. CONCLUSION

The following salient points are noteworthy from the emission test conducted on the CI engine with Cu-Zn-coated catalytic converter:

1. The CO emission was lowered by 60% at full load with a Cu-Zn-coated catalytic converter compared with a conventional CI engine without a catalytic converter. The copper catalyst is a good oxidizer agent for converting CO into CO_2.
2. The NO_x emissions were lowered by 65% at full load with a Cu-Zn-coated catalytic converter compared with a conventional CI engine without a catalytic converter. The zinc catalyst is a good oxi-reduction agent for converting NO into N_2 and O_2.
3. The HC emissions were lowered by 72% at full load with Cu-Zn-coated catalytic converter compared

with a conventional CI engine without a catalytic converter. The copper catalyst is a good oxidizer agent for converting HC into CO_2 and H_2O.

4. The proposed catalytic converter cost is 1.7 times lower than the existing catalytic converter.

The conclusions drawn above show that Cu-Zn-coated catalytic converters are cost-effective alternatives for the standard catalytic converters in emission reduction.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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