Experimental Investigation Towards Enhancement of Catalytic Converter by Modifying the Elements of Honeycomb Section

B. Saravanan, N. Natarajan, S. Deepankumar, S. Dhayaneethi, K. Vinithkumar, and S. B. Kumaragurubaran

1 Introduction

The air pollution posed a serious threat to the health. Poor air quality raises the risk of diseases such as asthma and bronchitis, as well as the chance of cancer. Every year, 30,000 people die as a result of air pollution [1]. Private vehicles have become a major source of pollution. Nitrogen oxides (NO—a harmful gas), carbon monoxide (CO—a source for acid rain and smog), and hydrocarbons are the main contaminants (HC—a cause of smog). Recent vehicles are fortified with a component known as a catalytic converter to minimize air pollution.

A chemical component that minimizes depleted emissions by catalyzing an oxidation reaction that converts toxic particulate emissions to less hazardous pollutants is called catalytic converter.

Although it is a pollution control device, it has been used in the exhaust systems of vehicles and lean-burn engines, electronic power systems, naphtha heaters, manufacturing stoves, and heavy machinery [2]. Its use is directly dependent on specific government responses to environmental, or health and safety laws. Carbon monoxide (CO), oxygen (O_2), and other hydrocarbons (HC) are mixed in these converters producing water (H_2O) vapors and carbon dioxide (CO_2). Catalytic converters also reduce the oxides of nitrogen (NO_x).

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B. B. V. L. Deepak et al. (eds.), *Recent Trends in Product Design and Intelligent Manufacturing Systems*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-19-4606-6_27

There are two types of catalytic converters.

- Two-way catalytic converter
- Three-way catalytic converter.

1.1 Advantages of Catalytic Converter

The approximate decrease in HC emission by 87% and NO_x emission by 62% for an entire span of an average vehicle is executed by the catalytic converter.

The aim of this project is to investigate alternative catalysts in order to improve catalytic converter emission conversion at the lowest cost. In catalytic converters, cerium (Ce), iron (Fe), manganese (Mn), and nickel (Ni) are also used. Modifications in the material of the catalyst used in a catalytic converter would be utilized to test emissions of different pollutants from a CI engine in this study. By undertaking these experiments, we will enhance engine performance by lowering pollutants like NO_x, CO, and HC, resulting in reduced air pollution than the current catalytic converter model.

The materials that replacing the noble are listed below

- Titanium dioxide (TiO_2).
- Cupric oxide (CuO).
- Calcium oxide (CaO).

The goal of this study was to eliminate NO_x, CO, and HC out of a diesel engine's exhaust gas. This was achieved by enabling exhaust gas to pass through a coated catalytic chamber with aluminum meshes layered in stacks coated with titanium dioxide, cupric oxide, and calcium oxide. The primary goal was to figure out how the catalytic converter performed, while the secondary goal was to see how the experiment's outcome and development comparison to earlier results. When compared to conventional catalytic converters, MCC is low cost, wide substrate area, and domestic availability that claims it be more competent in oxidizing/reducing pollutants.

2 Review of Literatures

The literature review has been done on the papers which is regarding to the exhaust gas emission using catalytic converter with different types of noble catalyst in accordance with their performance compared to the existing model of catalytic converter. So, the idea for the project work has been obtained by referring the different papers.

Warju et al. [3] analyzed the impact of a TiO_2-based metallic catalytic converter (MCC) in a four-stroke motorbike engine. When the TiO_2-based MCC is compared to traditional MCC Ph&Rh exhaust, it results in higher vehicle power and less fuel usage.

Shah et al. [1] implemented Cu_2O has been used in catalytic converters alongside noble metals like rhodium, palladium, and platinum, which resulted in a significant reduction in CO and HC emissions compared to the conventional system.

Reji et al. [4] evaluated the reduction of HC, CO, and NO_x pollution by means of exhaust gas recirculation (EGR) and catalytic converter; EGR has drastically reduced NO_x pollutants while the catalytic converter has reduced the level of HC and CO emissions.

Dey et al. [2] explored the reduction of carbon monoxide (CO) using a catalytic converter that uses the non-noble metal copper to substitute noble elements. CO oxidation is strongly controlled by the crystal size of catalysts and reduces as the crystallite size of the catalyst decreases. Increasing the temperature of the catalyzed reaction improves CO conversion rates unless the catalyst sinters.

Manojkumar et al. [5] have substituted the noble catalysts and tested the VCR engine under various loads. In comparison with the conventional catalytic converters, the catalytic converter having copper oxide characterizes both reduction and oxidation operations utilizing copper oxide only. Its major benefit over traditional catalytic converters is that the abundant obtainability of copper oxide and its cost-effectiveness, which eliminates the need for rare earth materials.

Hossain et al. [6] studied about reducing the amount of carbon oxides utilizing copper metal braced on titanium oxide nanotubes (TNT) catalysts was studied. In order to examine the activity of their proposed materials for ideal copper loading and ERC, the tests were made in home-made H-cell for the catalysts produced using 0.5 M Na-HCO_3 aqueous solution. Their improved oxidation stability, higher CO_2 adsorption capability, and stabilization of the reaction intermediate, layered titanates, are all factors.

Gadlegaonkar et al. [7] investigated the characteristics of the catalytic exchanger and engine efficiency after replacing noble catalysts with copper and modifying the catalytic converter architecture to lower backpressure in the engine without compromising engine efficiency. When alterations are made to the design, it allows the honeycomb to spread evenly and decreases backpressure while maintaining a consistent profile and enhancing the absorptive capacity of the honeycomb.

Atzl et al. [8] studied photocatalytic oxidizing, which includes using TiO_2 and UV light to convert NO_x to nitrates. The rates fluctuate immediately and are influenced by humidity levels, with a comparatively higher humidity indicating a improved adaptation. There was a notable change in irradiance likewise; when the brightness was raised, the conversion rate decreased.

Venkatesan et al. [9] developed a program that utilizes chemical reactions to reduce the intensity of harmful exhaust fumes to a more acceptable level. The noble catalyst is replaced by copper oxide in this system, which is installed in the engine exhaust. As an outcome, at 100% load, the highest reductions for HC, NO_x, and CO are 32%, 61%, and 21%, respectively.

Davis et al. [10] were studying the exhaust gas for the engine, investigated the effect of TiO_2 in lowering dangerous and poisonous gases and their effect on the environment. By studying the exhaust gas for the engine, they investigated the effect of TiO_2 in lowering dangerous and poisonous gases and their environmental impact.

Royer et al. [11] analyzed the catalytic reduction of carbon monoxide on metallic nanoparticles was investigated. It is necessary to catalyze CO oxidation in order to eliminate CO. The most active materials appear to be those comprising elements with very active single oxides (e.g., Cu and Co).

Kalam et al. [12] studied a novel catalytic converter for hydrocarbon engines that is built on catalyst materials that include metal-ions like cobalt oxide (CoO) and TiO_2 with a substrate of wire mesh. In comparison with the OEM catalytic converters, an estimation of decrease in CO and NO_x and increase in HC emissions was found in TiO_2/CoO-based catalytic converter.

Lanje et al. [13] copper oxide nanoparticles were synthesized and studied. CuO nanoparticles are made using copper acetate and NaOH in a fluid precipitation process. The rectangular morphology of CuO nanoparticles as synthesized was revealed by scanning electron microscopy (SEM). CuO nanoparticles as synthesized were 5–6 nm in size, according to electron microscopy (TEM).

Jang et al. [14] have studied the influence of size of particles, and elemental composition of TiO_2 nanoparticles on the characteristics of photocatalysts was investigated. The photocatalysts characteristics of TiO_2 nanoparticles, such as breakdown of methylene blue and bacteria and dissolution of ammonia gas, were studied in terms of anatase mass fraction and particle size.

Neeft et al. [15] have studied impact of interaction among catalyst and soot, as in the reactivity with a gas (oxygen) of a solid (soot) over another (the catalyst). The goal of their research was to test candidate catalysts for their activity in the oxidizing of soot in a systematic manner. CaO can also be converted to an assorted calcium oxide or calcium hydroxide or calcium carbonate, while PbO can be converted to a mixed oxide/carbonate. According to TGA mass loss, $CaCO_3$ is generated first by the reaction of CaO with soot deposits that decays at higher temperatures to CO or CO_2 and CaO.

3 Objective

The main objectives of our project are to understand the concept and working of catalytic converter and overcome the negative aspects. To determine pressure and velocity analysis of catalytic converter. To minimize the backpressure effect on the engine. To examine the value of the exhaust gases after changing the materials.

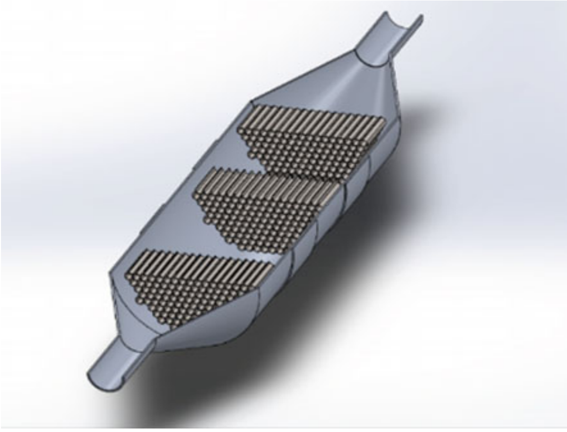


Fig. 1 Cut section of catalytic converter

4 Experimental Setup

4.1 Designing of Catalytic Converter

The designing of catalytic converter for changing noble catalysts with nanocatalysts and reducing the backpressure has been made using SOLIDWORKS is shown in Fig. 1. The honeycomb section was replaced by using the aluminum meshes. For that, the aluminum baffle plates are cut into circular pieces in 4 in. diameter. The thirty set of coated aluminum baffle plates which are coated with TiO_2, CuO, and CaO, respectively, in the distance of 3 in.

4.2 Material Selection

The materials selected for the study of enhancement of catalytic converter are listed in Table 1.

Table 1 Materials selection

Materials selected	Purpose
Nanocatalysts	Titanium dioxide (TiO_2) Cupric oxide (CuO) Calcium oxide (CaO)
Insulator	Glass wool
Serpentine chamber/converter chamber	Aluminum wire mesh/baffle plate
Housing	PVC pipe

Fig. 2 Aluminum wire mesh—substrate

4.3 Material Selection

4.3.1 Catalyst

Many standard solutions with diversified weight ratios and aqueous molar ratios were made use in our work. CuO, TiO_2, and CaO were implemented as a catalyst of metal oxide. The reducing agent was identified as CuO, while the oxidizing agents were identified to be CaO and TiO_2. The inertness to form sulfate and properties of surface that makes it favored transporter in chosen catalytic reduction reaction of CO, NO_x, and from the still sources of pollution.

4.3.2 Substrate

Aluminum is the chosen material for substrate and is shown in Fig. 2. It is most widely implemented in vehicle exhaust, because it has more advantages comparing other metals and it also low-cost metal. The substrate to be used for the catalytic converter must have high-physical properties and high-melting point. Aluminum is selected for its betterment in its physical and chemical properties which has the melting point of about 600 °C.

4.4 Substrate of Wire Mesh—Treatment

To remove all the impurities from the substrates of wire mesh, they were dipped for half-an-hour into a dilute solution of 10% hydrochloric acid (HCl). Before drying at 100 °C in an oven, the substrates were rinsed in distilled water. It takes almost one hour for the drying process before it is coated with the catalyst.

5 Nanocatalysts

Nanocatalysts aid in the scientific problem of catalysis in the field of nanotechnology. Exploration of efficient catalytic processes, particularly nanocatalysis, is one of the main areas for reaching this goal. Alternative activation methodologies, such as mechanochemical mixing, microwave and ultrasonic irradiation, and the use of nanocatalysts with magnetic cores, could all be part of the desired approach; environmentally friendly applications in catalysis could be best addressed via magnetically recoverable and recyclable nanocatalysts for oxidation reduction and condensation reaction.

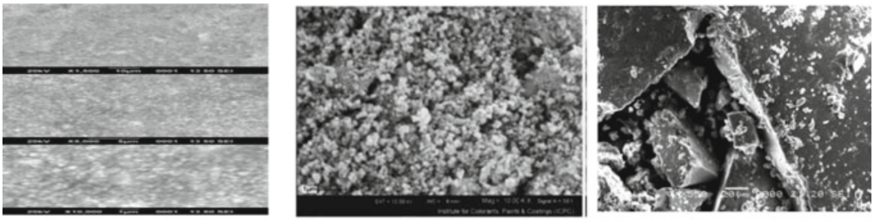
In this study, a catalytic converter based on TiO_2/CuO/CaO materials was created to oxidize, decrease, and absorb NO_x, HC, and CO emissions. As oxidizing catalysts, pure TiO_2 and CuO are employed, whereas CaO is used as a reducing catalyst.

5.1 Titanium Dioxide, Calcium Oxide, Copper Oxide

TiO_2, as a bulk substance, is a food additive. Small sized main particle may benefit TiO_2, and the percentage of TiO_2 produced in or near the nanorange is predicted to rise significantly. CaO nanoparticles are easier to work with than homogenous base catalysts. In this cyclization reaction, CaO nanoparticles are the most effective catalyst. The larger surface area of nanomaterials accounts for the improved catalytic activity of CaO nanoparticles over commercially accessible bulk CaO. Because of their surface characteristics, CaO nanoparticles have a highly effective catalytic activity. The nanoparticles of CuO are seen as product of high interest because of their efficacy in heat transfer applications a nanofluids. Recent reports have been made regarding the nano-chemical approach, one-step solid-state reaction method at ambient temperature, technique of sol–gel, pre-cursors thermal deposition, and co-implementation of oxygen ions and metal among others.

5.2 SEM Test of TiO_2, CaO, CuO

In the presence of UV light, a sample of the TiO_2 mixed paint coated tile was collected in a sample vial and sealed. The particles are rectangular in shape and range in size from 25 to 75 nm. In the sample bottle, a sample of the CaO coating mixture was collected and sealed. The particles in this sample are spherical in shape and have a size of 30–40 nm, according to the analysis. In the sample bottle, a sample of CuO coating mixture was collected and sealed. The SEM image of the materials used in metallic catalytic converter as shown in Fig. 3 demonstrates that the particles in this sample are rectangular in shape and have a size of 5–6 nm, according to the analysis.



(a) (b) (c)

Fig. 3 SEM image of **a** TiO_2, **b** CaO, **c** CuO

Table 2 Properties of materials for metallic catalytic converter (TiO_2, CaO, and CuO)

Properties	TiO_2	CaO	CuO
Purity (%)	98.5	96.5	96
Particle size (nm)	25–75	30–40	5–6
Color	White	White	Brownish black
Thermal conductivity (W/m K)	4–11	2.5	33
Density (g/cm^3)	4.23	3.3	6.31

The properties of TiO_2, CaO, CuO used in this process have been shown in Table 2.

6 Result and Discussion

6.1 NDIR Analyzer and Exhaust Gas Analyzer

An NDIR analyzer and an exhaust gas analyzer were used to examine the catalytic converter. The non-dispersive infrared (NDIR) analyzer is a gas detecting sensor that measures gas concentrations in the surrounding atmosphere and examines CO and CO_2 emissions from engine exhaust, whereas the exhaust gas analyzer tests NO_x and HC emissions. The production of the emissions studied is quantified in parts per million (ppm).

The emission characteristics of a CI engine are investigated at different speeds with constant loads, and hence, the following efforts have been reported.

1. For various loads, the engine was run without a catalytic converter.
2. For various loads, the engine is equipped with a conventional and metallic catalytic converter.
3. For various speeds, the engine is equipped with a conventional and metallic catalytic converter.
4. Different speeds were achieved without the use of a catalytic converter.

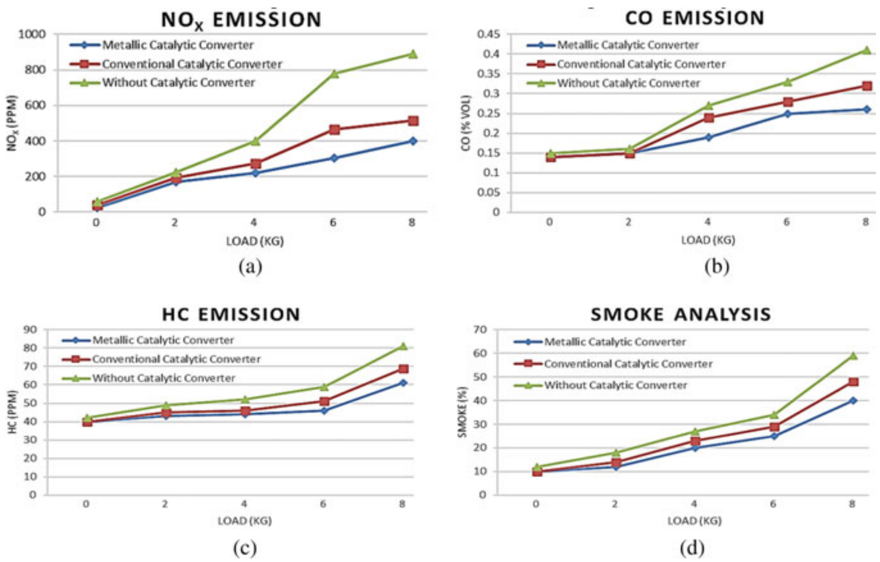


Fig. 4 Emission results. **a** NO_x, **b** CO, **c** HC, **d** smoke analysis

6.2 Study of NO_x, CO, and HC Emission

The concept is based on the response of a water–gas shift-fuse and the responses of steam transforming. Figure 4a shows that the usage of a CuO-based catalytic converter results in a 61% reduction in NO_x. NO_x is broken down into nitrogen (N_2) and carbon dioxide (CO_2). With the use of a catalytic converter, CO is reduced by around 21% which is illustrated in Fig. 4b. CO_2 is formed when CO is oxidized. When the nanocatalysts in the catalytic converter react with CO, they reduce it to carbon-di-oxide and cause Cu and Cl to be deposited due to CO's reduction property. The reduction of hydrocarbons by a conventional catalytic converter is because of the fact, a small amount of fuel in a big volume of air results in lower CO and HC emissions. H_2O and CO_2 are produced when HC is oxidized as represented in Fig. 4c.

6.3 Smoke Analysis

The reduction of smoke emissions utilizing a catalytic convertor is seen in Fig. 4d. Soot or smoke consisting of μm in diameter particles. Particulate matter has a variety of severe health impacts, including respiratory disorders and cancer. Smoke has a density of about 38 kg/m^3. The use of a catalytic converter with nanocatalysts reduces smoke by roughly 32%.

6.4 Speed Analysis

For each attempt, engine metrics like as HC, NO_x, and CO, and the efficiency of the conversion are plotted for various speeds. Figure 5a depicts the variance in NO_x emissions as a function of engine speed. It is clear that reduced NO_x emissions are achieved only slightly with the help of a catalytic converter. With the application of a catalytic converter, the NO_x level does not change significantly. This is because the CO and HC emissions are oxidized by a copper-coated catalyst. The emissions of HC and CO from an engine without a catalytic converter are significantly higher. Due to the decreased bed temperature of the catalytic converter, CO emissions are first reduced only somewhat. The CO level drops by roughly 2.5% by volume after 30 km/h as shown in Fig. 5b. This is owing to the significant influence of higher bed temperature, which is caused by the metal-supported catalyst converter's ability to achieve the temperature of the light faster. The catalytic converter bed's temperature rises as a result of the converter's resistance to the chemical activity in the bed and the flow of exhaust gases. When compared to a regular engine, the catalytic converter reduces HC levels uniformly, resulting in a reduction of around 100 ppm when the engine speed is maximum as represented in Fig. 5c.

A reduction in NO_x, HC, and CO is achieved as a result of the appreciable reduction in NO_x emissions as summarized as a decreased value of about 300 ppm at the maximum engine speed.

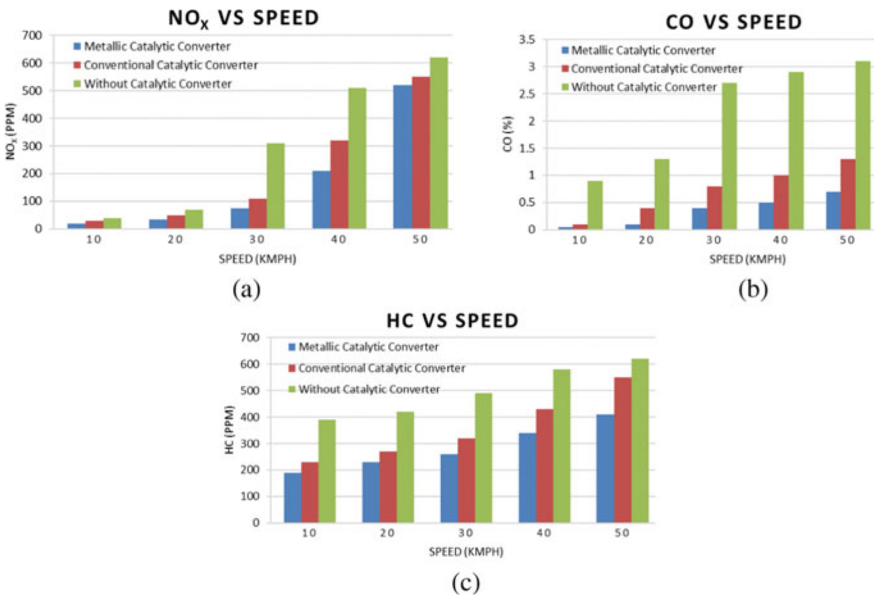


Fig. 5 Emissions versus speed. **a** NO_x, **b** CO, **c** HC

7 Conclusion

The most important findings of the experimental study are summarized here. The following observations were made as a result of the aforesaid analysis. When a catalytic converter is installed on an engine, CO and HC emissions are dramatically reduced. In comparison with an engine without a conventional catalytic converter (CCC), the volume CO, 300 ppm NO_x, and 100 ppm HC are reduced by 2.5%. When the engine is permitted to operate with a metallic catalytic converter (MCC) at complete loads, NO_x levels are dramatically decreased. When the emissions are compared without a catalytic converter and conventional catalytic converter (CCC), the result reveals an extreme reduction of 61% in NO_x emissions in maximum operating condition of 8 kg load.

When the emissions are compared of a metallic catalytic converter (MCC) with nanocatalysts to that of a catalytic converter without nanocatalysts at all loads, that is clear that hydrocarbon emission is reduced. At full load, the highest reduction in HC is recorded to be 32%. A significant reduction in smoke and CO emissions where achieved when analyzed with those engines without a conventional catalytic converter (CCC) and nanocatalyst-based catalytic converters demonstrates. At full load, the highest drop in smoke and carbon mono oxide (CO) is measured to be 32% and 21%, respectively.

As a result, we may conclude that the catalytic converter with nanocatalysts outperforms current OEM catalytic converters. In comparison with the OEM catalytic converter, the catalytic converter with nanocatalysts emits less, is less expensive, and has lower backpressure. As a result, a catalytic converter including titanium oxide, cupric oxide, and calcium oxide as catalysts will reduce NO_x, HC, and CO emissions to an acceptable level.

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