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Experimental Investigation of Activated Carbon-Basedtwo-Way Catalytic Converter For Its Emission Characteristics In Two-Wheeler Applications

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Abstract

Catalytic converters are combination of platinum, palladium and rhodium (Platinum Group Metal). With the existing scenario of precious metal prices, a good trade-off between cost and performance exists. This work is an effort to find substitutes cheaper to the precious metals without much compromising on the performance of the catalytic converter.

In this work the two-way catalytic converter is designed and evaluated for emission conversion efficiency using AiRREX HG-540 emission gas analyzer.The two-way converter reactor isimpregnated with activated carbon using binding agent epoxy in the slurry. The activated carbon adsorbs carbon monoxide and unburnt hydrocarbon. The performance of the made-up converter is then evaluated by mounting it on a test vehicle (Royal Enfield Electra 350cc) for its emission characteristics.

The test shows significant reduction in the emission values of the HC, CO and CO_2 when tested with activated carbon impregnated catalytic converter with that without catalytic converter. Reduction of hydrocarbon emission to 218 ppm from 1751 ppm was observed.

Keywords: Two-way Catalytic converters, Activated Carbon, Impregnated, Emission characteristics, Two-Wheelers.

1. Introduction

Pollution is a major concern regarding the hazards caused by industrial, automobile. Off the causes of pollution in the environment, emission from the automobile holds a substantial amount. Number of vehicleseverywhere has enlarged from about 40 million to over 1300 million in last 60 years [1]. The ecologicalworrycreated by vehicles is because maximum engines use burning of fuels resultant from crude oil as a main source of energy. Burning of hydrocarbon (HC) supposedly leads to the reaction of creation of water and carbon dioxide. Though, due to opposed combustion control and the higher temperatures attained in the combustion space, the exhaust out of combustion chamber contains large amounts of pollutants. In recent years, both governments and consumers have become more concerned about the effect automobile emission use on climate change and global warming.

The automotive industry has responded to the growing concerns on combustion process and it, force by looking for new technologies to make internal combustion engines more fuel-efficient and produce fewer emissions.

In line, it intends for the use of activated carbon as a catalyst replacing platinum group metals in the catalytic converters. Mainly, recent developments in the field of the three-way type of catalysts, i.e. NM/CeO_2–ZrO_2–Al_2O_3 containing systems; insight on the lean-DE NOx and diesel engine combustionis explored [2].

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Highly Porous carbon materials included activated carbons and have carbons synthesized by hard and soft temporary plating methods have been used in a variety of applications. The analysis provides the idea to which limit carbons have been used as the material for catalyst support in the fields of energy and environmental chemistry [3]. Therefore, activated carbon coated with palladium as the catalyst for the oxidation of carbon monoxide under ambient air condition was evaluated for holding after 3.75 and 7.5 months for 1005 conversion as assessed by Beer Singh et al. (2009) [4].
Research conducted by Eric J. Peterson et al. (2012) [5] used Palladium as catalyst over alumina with the addition of lanthanum for its stability. Ionic palladium has high-temperature stability and low-temperature exhaust treatment catalyst. Palladium interaction was studied A.I. Boronin et al. (2009) [6] over Cerium oxide used as support catalyst for palladium catalyst. The fabricated catalytic converter performed well for high and low-temperature activity in carbon monoxide.
The experiment conducted by HU Chunming et al. (2008)[7], the three-way catalytic converter was tested using platinum, palladium, rhodium as the catalyst. Lanthanum-alumina used with for high surface area cerium (0.55%), zirconium (0.355), yttrium (0.05%), lanthanum (0. 05%).It resulted in a low-temperature activity.
The effectiveness of carbon materials as activated carbon, carbon nanotubes, nanofibers used as support catalyst is explored by many researchers [3; 8]. Catalytic converter maintains the converter temperature above its operating temperature [8] and helps for the cold start which act as a shortcoming while using activated carbon as a catalyst.
Automotive catalytic converters subjected to different driving cycle, fluctuation air-fuel ratio, flow lag of feedback system analyzed for catalyst's performance near stoichiometric conditions[9]. Titanium oxide as support catalyst for reduction and oxidation at low pressure and temperature. It was found that titanium oxide is having strong metal-support interaction and chemical stability[10]. Using hydrogen peroxide to obtaining activated carbon from coconut peel and activated carbon provided more space for the catalyst as support catalyst[11].
The experiment was performed to analyze the performance of porous charcoal in the absorption of carbon dioxide[12]. It was found that the bamboo charcoal had the best adsorption capacity, which resulted in significant reduction in CO_2 concentration. A brief comparison between results established by various researchers by using different types of catalysis support is shown in Table 1.
This study scientifically reviews the current state of knowledge about air pollution caused by four-stroke gasoline engine combustion. The objective of the survey is to explore the application of platinum group metal as catalyst and replace it with activated carbon and the possibility of decreasing the engine emission without decreasing the engine performances. A comparison between the various types of catalysis support being used in catalytic converter nowadays with that of carbon used in this study is shown in Table 2.
Another objective of this study to evaluate the effectiveness of the catalytic converter to be fabricated for two-wheelers applications and compare with that of without using catalytic converter. For this, the catalytic converter was coupled with Royal Enfield 350cc engine and the effect of different emission using a gas analyzer were measured. The experimental procedure of this catalytic converter system is necessary to characterize the catalyst and to optimize the emission of gasoline four-stroke engine.

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Table 1. **A brief comparison between results established by various researchers by using different types of catalysis support.**

Ref.	Type of catalysis support	Catalytic Conv.	Experimental condition	Emission results
Eric J. Peterson et al. [5]	Palladium/Lanthanum oxide-alumina coated reactor core.	Inorganic catalytic converter	Study the effect of lanthanum oxide to the alumina since known for its ability to improve alumina stability. Carbon monoxide oxidation reaction shows catalytic activity at 40°C.	There are high-temperature stability and regeneration ability of these Palladium ions make this catalyst system of interest for low-temperature exhaust Treatment catalysts.
A.I. Boronin et al. [6]	Palladium, Ceria CO oxidation.	Inorganic catalytic converter	Investigate the synthesize palladium–ceria catalysts for CO oxidation at lower temperature by physicochemical methods, and their catalytic performance.	The rate of conversion of carbon monoxide increases with the rise in temperature till more than 200 degrees Celsius for the considered composition of the catalyst.
Chunming HU et al. [7]	Zirconium, Yttrium, Cerium, Lanthanum oxide ($Ce0.55Zr0.35Y0.05La0.05O_2$) with platinum, palladium, rhodium powder was coated on a honeycomb cordierite (46 cells/cm^2), dried, calcined at 550ºC for five h.	Inorganic catalytic converter	The catalytic performance of the catalysts for light-off and complete conversion for temperatures about 30000 hours.	The exhaust of simulated gas was a mixture of O_2, NO (0.12%), CO (0.86%), H_2O (10%),C_3H_8 (0.06%), N_2, and CO_2 (12%)
A. K. Srivastava et al. [13]	Carbon was impregnated with palladium salt to get Pd/C catalyst.	Catalyst palladium and carbon	Removal ofCarbon monoxide (CO) is carried out using activated carbon-based palladium impregnated catalyst (Pd/C).	Palladium in optimum content was found to be 6.5% for providing protection against CO gas.
Zongcheng ZHAN et al. [14]	Cerium oxide and Platinum	Inorganic Catalytic Converter	To study the oxygen storage capacity of the three-way catalytic converter.	Oxygen storage capacity declines with the length of catalytic converter and age of catalyst.
Biniwale, R.B et al. [15]	Platinum Group Metal.	Inorganic catalytic converter	For estimating the effective amount of catalyst for catalytic conversion of carbon removalmonoxide and nitrogen monoxide.	The conversion of NO to N_2 occurs with the CO oxidation reaction. Whenthe surface area of the catalyst is large, CO is converted to CO_2, partial pressure and surface cover of CO drop to almost zero.

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J. Kim et al. [16]	Carbon supported palladium.	Oxidation catalytic converter.	To estimate the effectiveness of carbon supported palladium catalyst.	CO oxidation showed that 5% Pd supported on CeO_2, ZrO_2 have a CO to CO_2 conversion of 100%

Table 2: A comparison between the various types of catalysis support being used in catalytic converter nowadays with that of carbon used in this study.

Category of catalysis support	Advantages	Shortcomings
Polymer (Organic acid; Enzyme's)	• Polymer containing aryl group has adaptablecharacteristics. • Variety of physical possessions like sponginess, surface area, and categorized solution.	• Low heat transfer capability. • Possess mechanical possessions which stop it from the maceration. • Commercial polymers may contain unfamiliar impurities. • Physical properties may differ.
Metal	• Encourage some catalytic activity as a similar catalyst. • Separation from the product is easy. • Produces less corrosion.	• Leakage problem by the Van de Waals link amongst the catalyst.
Carbon	• Being porous it harvests high surface area. • Minorquantity of chemically bonded heteroatoms	• Cannot beemployed for hydrogenation reaction >700 due to possibility of yielding of methane and CO_2.

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2. Design Consideration and Mathematical Calculations

Table 3 shows the specification of test vehicle (Royal Enfield 350cc) used for the investigation of emission from the engine to design correspondingly efficient catalytic converter to work efficiently.

Table 3. Test vehicle engine specifications

Type	Single Cylinder, four strokes, Twin spark
Displacement, cc	346
Bore x Stroke, mm	70 x 90
Compression ratio	8.5:1
Maximum Power, bhp	19.8 @ 5250 rpm
Maximum Torque, Nm	28 @ 4000 rpm

2.1 Designing Parameters and used equations

The steps followed for calculation of exhaust emission and size of catalytic converter to accommodate the rate of flow from the catalytic converter for a 350cc test vehicle are listed below.

- Determining the mass flow rate of fuel,(m_f)
- Determining the mass flow rate of air,(m_a)
- Mass flow rate of exhaust gas, (m_{exh})
- The size of the exhaust pipe.
- Determination of catalyst volume, ($V_{Catalyst}$)
- Dimension of the shell (Length and Diameter)
- The rate of adsorption.

Various assumptions have been made for designing the catalytic converter suitable for the two-wheeler application as shown below. Further the thermodynamic properties adopted for the designing purpose is shown in table 4.

Assumptions

i. Mileage as specified by the manufacturer=40km/litre
ii. Taking average speed=60km/hour
iii. Time required for consumption of 1 litre gasoline=2400sec
iv. Stoichiometric Air-Fuel ratio

a. Thermodynamic Properties

The function of Freundlich: $\frac{x}{m} = k_f C_e^{1/n}$

Where; $\frac{x}{m}$ =adsorbed substance per gram active carbon

C_e= concentration difference (between before and after)

k_f, n = specific constant

Table 4. Thermodynamic properties used for designing the catalytic reactor.

Thermodynamic properties	Values
Molar mass (kg/mol)	28.96
Density (kg/m^3)	1.205
Specific heat capacity (J/kg. K)	1005

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Dynamic viscosity (kg/m. s)	18.207×10^{-6}
Thermal conductivity (W/m. K)	0.0257

b. Mass flow rate of fuel (m_f)

$$m_f = \frac{Fuel\ Consumed\ in\ m^3 \times density\ of\ fuel}{time\ required\ (t)}$$

= $0.3083 \times 10^{-3}\ {kg}/{s}$

Where, m_f =mass flow rate of fuel(kg/s)

Density of fuel= 740 ${kg}/{m^3}$

c. Mass flow rate of air(m_a):

m_a= 4.312 × 10^{-3} kg/sec

d. Exhaust mass flow rate(m_{ex})

m_{exh}= 4.6110×10^{-3} kg/sec

2.2 Design calculations

For designing the cylindrical shape for fabrication of the catalytic reactor impregnated with activated carbon following designing calculation were employed.

Space velocity (Holding or Residence time): It isthe time essential for processing one reactor volume of fluid. For single cylinder engine it could be assumed as 20000 hr^{-1}

Space velocity = $\frac{volume\ \ flows\ \ rate}{catalyst\ \ volume}$

Volume flow rate

= swept volume × number of intake stroke/hr.

=15.578325m^3

Catalyst volume= $\frac{volume\ \ flow\ \ rate}{Space\ \ Velocity}$

$V_{Catalyst}$ =778.916 ml

Dimension of Shell

The inlet and outlet cones hold the cylindrical part known as the shell.

$V_{Catalyst} = \frac{\pi}{4} \times D^2 \times L\ , mm^3$

Where, D= Diameter of the catalyst

L= Length of the catalyst (assume L=2D)

$$0.000778916 = \frac{\pi}{4} \times D^2 \times 2D$$

D = 0.07916448131m ≈ 79.1645 80 mm

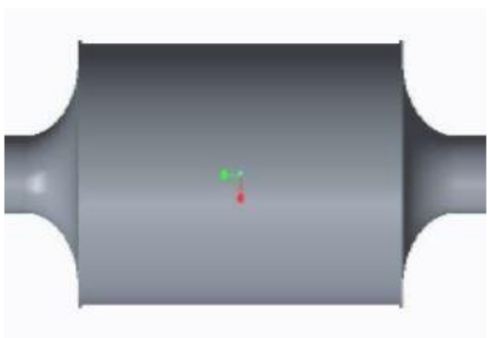
L = 2×80 = 160mm

Length of the shell = 160mm

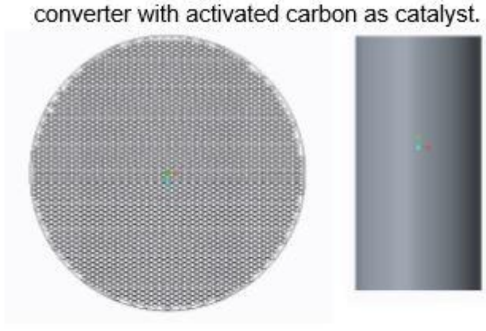
Diameter of inlet exhaust pipe = 0.69 inch or 18 mm.

3. Experimental Setup

The design and experimental setup of the catalytic converter employed with activated carbon in the ceramic substrate enclosed in a steel casing is shown in the Fig. 1. The size of the catalytic converter is in accordance with the calculated design and exhaust flow rate from the 350cc single cylinder engine. The specifications of the engine are shown in Table. 3. For determining the size and mounting of the catalytic converter on the vehicle CAD model was prepared highlighting the ceramic substrate and dimension of the designed catalytic converter. The process of coating the activated carbon on the ceramic substrate involves the rolling of the sheet to the dimension for the casing. Activated Carbon is prepared and then mixed with the binding substance epoxy. The ceramic substrate is the dipped in the slurry and is allowed to cure till the mix gets hard. The ceramic substrate is then enclosed within the steel casing with a layer of insulating material asbestos. With proper ensuring for the leak proof behavior the enclosure is welded to the inlet and outlet part of the casing.The prepared model and its mounting on the Royal Enfield 350cc bike are shown in fig. 2. Testing is carried out at the PUC centre with activated carbon catalytic converter and without mounting catalytic converter. The analyzer used for the testing is AiRREX HG -540 automotive emission analyzer for detection of exhaust emissions from the vehicle.



a. Steel casing of the prepared catalytic converter with activated carbon as catalyst.



b. Top view and Side view of a prepared model showing the ceramic substrate inside a Catalytic converter.

c. Fabricated catalytic converter with activated carbon as catalyst on its ceramic substrate

d. Mounting of catalytic converter on Royal Enfield 350cc bike for testing purpose.

Fig. 1 Design and Testing of catalytic converter impregnated with activated carbon in the ceramic substrate enclosed in a steel casing.

Result and Discussion

A. CO_2 Emission

As can be noted from Fig. 2 there is a significant reduction in the CO_2 level from the exhaust when the test vehicle is employed with the catalytic converter impregnated with activated carbon on its substrate. This might be due to the standing properties of activated carbon like high porosity and high adsorption capacity towards the pollutants. Catalyst also showed high-temperature stability and regeneration ability which makes this catalyst system of interest for low-temperature exhaust treatment purposes.The is a significant reduction from 20 % (by v/v) to 3% when the test vehicle was employed with impregnated carbon on the ceramic substrate when compared with that of without using catalytic converter condition.

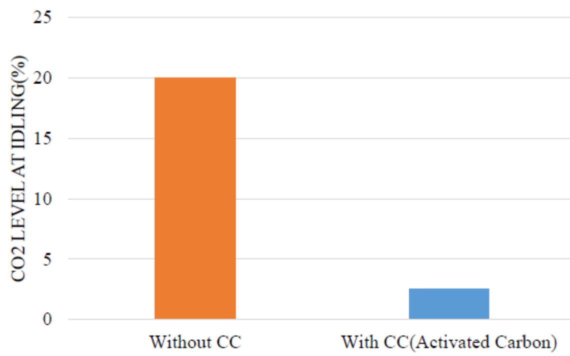


Fig. 2 Carbon dioxide emission level with catalytic converter impregnated with activated carbon and other without employing catalytic converter at idling speed.

B. CO Emission

As can be seen from Fig. 3 there is a sharp decline in the levels of carbon monoxide emission from the test vehicle when the made-up catalytic converter at the tail is employed. A significant reduction of CO emission from 0.429% to 0.089% was observed. This might be due to activated carbon usefulness derives from its large micropore volume and results in high surface area.

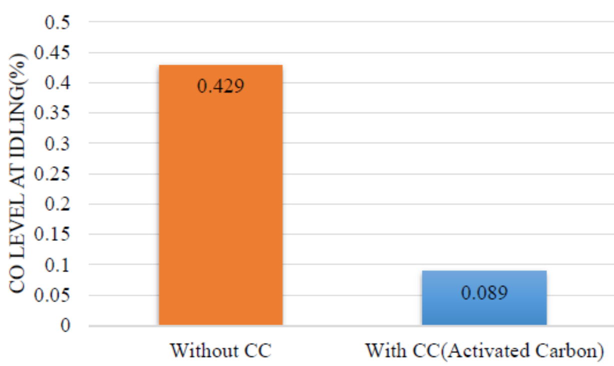


Fig. 3. Carbon monoxide emission level with catalytic converter impregnated with activated carbon and other without employing catalytic converter at idling speed.

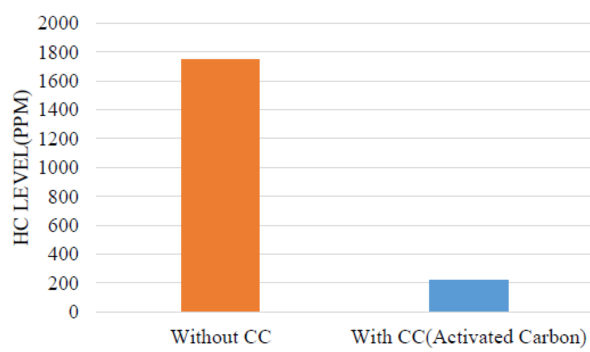


Fig. 4. Hydrocarbon emission level with catalytic converter impregnated with activated carbon and other without employing catalytic converter at idling speed.

C. HC Emission

The HC emissions finds its source of formation from improper combustion (lack of oxygen; crevice volume; lower combustion temperature) inside the combustion chamber. As can be seen from Fig. 4 there

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is a sharp decline in the levels of unburnedhydrocarbon emission from the test vehicle when the made-up catalytic converter at the tail is employed. A significant reduction of HC emission from 1751 ppm to 218 ppm was observed. This might be due to the standing nature of the carbon which absorbs heat as the exhaust gases pass through it. Further, due to the large surface area of activated carbon it raises the temperature of the substrate as a result lowering the HC emission action as a source of secondary combustion for HC.

Conclusions

From the investigation been conducted using the made-up activated carbon based two-way catalytic converter in two wheelers following conclusion can be made.

1. The is a significant reduction from 20 % (by v/v) to 3% when the test vehicle was employed with impregnated carbon on the ceramic substrate when compared with that of without using catalytic converter condition.
2. A significant reduction of CO emission from 0.429% to 0.089% was observed.
3. A significant reduction of HC emission from 1751 ppm to 218 ppm was observed.

As in the present study the experimental investigation of emission performance of activated carbon impregnated catalytic converter is done. A detailed experimental study on the high temperature and low temperature stability should be a future scope of this study. Further, the catalytic converter efficiency during cold starting employing activated carbon support palladium ceramic substrate can be explored.

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