ISSN 2395-1621

Emission Reducer Device Catalytic Converter

[#1]Prof. M.V. Khot, [#2]Ajinkya R. Sonawane, [#3]Nandkishor D. Gawali, [#4]Prasad M. Mete, [#5]Ganesh T. Sawake

[1]ajinkyasonawane18@gmail.com,
[2]anandgawali11@gmail.com,

[#1]Department of Mechanical engineering, TSSM's P.V.P.I.T, Maharashtra, India
[#2]Prof & HOD, Department of Mechanical Engg.
411021, Bavadhan Dist. Pune

ABSTRACT

Air pollution generated from mobile sources is a problem of general interest. Vehicle population is projected to grow close to 1300 million by the year 2030. It's an important issue from point of view of green house effect. Due to incomplete combustion in the engine, there are a number of incomplete combustion products CO_x, HC, NO_x, particulate matters etc. These pollutants have negative impact on air quality, environment and human health that leads in stringent norms of pollutant emission. Numbers of alternative technologies like improvement in engine design, use of alternative fuels, fuel additives, exhaust treatment or better tuning of the combustion process etc. are being considered to reduce the emission levels of the engine. Among all the types of technologies developed so far, use of catalytic converters based on platinum (noble) group metal is the best way to control automotive exhaust emissions. This review paper discusses automotive exhaust emissions and its impact, automotive exhaust emission control by platinum, palladium & rhodium metals, catalytic converter's types, it's limitations & also achievements of catalytic converters.

ARTICLE INFO

Article History

Received :24th May 2016

Received in revised form :

26th May 2016

Accepted : 28th May 2016

Published online :

1st June 2016

Keywords — Catalytic Converter, Catalyst, Platinum group metal, Exhaust emissions

I. INTRODUCTION

A catalytic converter is a vehicle emissions control device which converts toxic by-products of combustion in the exhaust of an internal combustion engine to less toxic substances by way of catalyzed chemical reactions. The performance of a specific catalytic converter analyzing the emitted exhaust gases (NO, NO_2, CO, CO_2, O_2, SO_2) of a CI engine at different engine speed and torque. From different graphical representations it is very clear that the catalytic converter reduces CO_2, NO_2, & SO_2 emission in a large extend. In addition, it minimizes the CO & NO emission at a specific engine speed.The catalytic converters for the first time were used to reduce only HC and CO emissions from the US gasoline passenger cars in 1975. As these converters reduced HC and CO by oxidation, they were called as 'oxidation' catalytic converters. NO_x emission standards were met by use of EGR at that time. The engines were operated on rich mixtures and with application of EGR engine out NO_x emissions were reduced. Secondary air was injected in the exhaust system upstream of the converter to provide sufficient oxygen for oxidation of CO and HC on the catalyst. Later, when the NOx standards were made stringent from 1981, reduction catalysts were also developed. An exhaust gas oxygen sensor developed in the early 1980s facilitated engine operation at near stoichiometric mixtures that made it possible to simultaneously oxidize CO and HC to CO_2 and H_2O and reduce NO_x to N_2. This review paper discusses automotive exhaust emissions and its impact, automotive exhaust emission control by platinum (noble) group metal based catalyst in catalytic converter, history of catalytic convertor, types of catalytic convertor, limitation of catalytic convertor and also achievements of catalytic convertor.

II. CATALYTIC CONVERTER

Regardless of how perfect the engine is operating, there will always be some harmful by product of combustion. That's why the necessities use of three way catalytic converter (TWC).

Essentially, the catalytic converter is used to complete the oxidation process for hydrocarbon (HC), carbon monoxide (CO), in addition to reducing oxides of nitrogen (NO_x) back to simple nitrogen & CO_2.

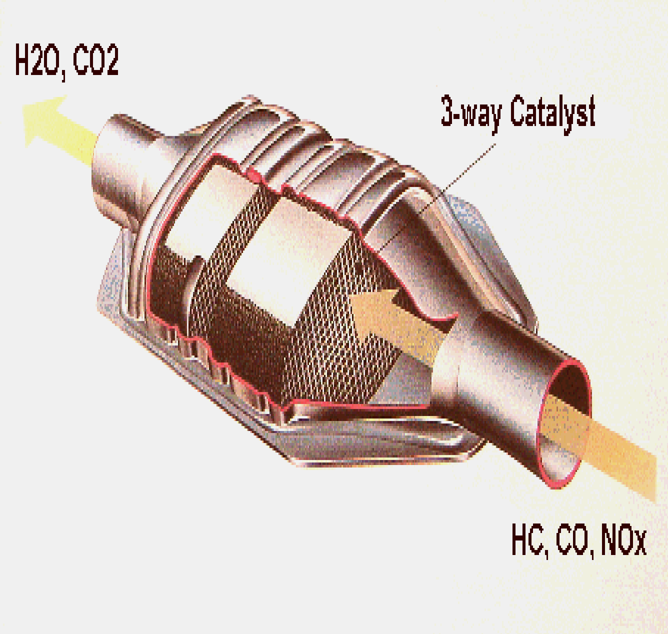


Fig. THREE WAY CATALYTIC CONVERTER

Types of Catalytic Converter:

- TWO WAY CATALYTIC CONVERTER

A two-way catalytic converter has two simultaneous tasks:

1. Oxidation of carbon monoxide to carbon dioxide:
   2CO + O2 → 2CO2
2. Oxidation of unburnt hydrocarbons (unburnt and partially-burnt fuel) to carbon

dioxide and water:

CxH2x+2 + 2xO2 → xCO2 + 2xH2O (a combustion reaction)

This type of catalytic converter is widely used on diesel engines to reduce hydrocarbon and carbon monoxide emissions.

- THREE WAY CATALYTIC CONVERTER

Since 1981, three-way catalytic converters have been used in vehicle emission control systems in North America and many other countries on road going vehicles. A three-way catalytic converter has three simultaneous tasks:

1. Reduction of nitrogen oxides to nitrogen and oxygen:
   2NOx → xO2 + N2
2. Oxidation of carbon monoxide to carbon dioxide:
   2CO + O2 → 2CO2
3. Oxidation of unburnt hydrocarbons (HC) to carbon dioxide and water:
   CxH2x+2 + 2xO2→ xCO2 + 2xH2O

- Modern Three way catalytic converter

A typical design of a modern three-way catalytic converter is a stainless steel container that incorporates a honeycomb monolith made of ceramic or metal. The monolith acts as the inert substrate coating with washcoat and active catalysts. Washcoat is a layer of mixture (mainly aluminum) which gives a further irregular and larger surface area also contains oxygen storage promoters and stabilizers. To prepare the active monolith, a layer of washcoat is first deposited on the substrate and the catalysts are then deposited on the washcoat or dipping the monolith into a slurry containing washcoat components and platinum group metals. The excess of the deposited material (washcoat) is removed using high-pressure air or by applying a vacuum. Then the monolith is calcined to obtain the finished catalyst. The monolith's geometrical characteristics play a key role in effecting the distributions of temperature and species throughout the device and then determining the efficiency of the converter. It combines the requirements of compactness, high volumetric flow rates and low back pressure. Palladium has a lower sintering tendency than platinum at high temperatures of about 980 ^{0}C in the oxidizing atmosphere. Rhodium is primarily a NO reduction catalyst. The NO reduction activity of noble metals is in the order Rh>Pd>Pt. when simultaneous conversion of CO, HC and NO_x is desired in the 3-way catalytic converters, mixture of Pt + Pd is used with Rh in a ratio of 5:1 to 10:1. The active metal in the automotive catalysts Pt, Pd and/or Rh is very small (0.1 to 0.15 % by weight of monolith). The particle size of the noble metal particles when fresh is around 50 nm or smaller. At high temperature the noble metals sinter and particles may grow to a size of around 100 nm.

Substrate:

Catalyst:- The catalyst include oxides of base metals e.g. copper, chromium, nickel, cobalt etc. and the noble metals platinum (Pt), palladium (Pd) and rhodium (Rh). Base metal oxides although found to be effective at higher temperature but they sinter and deactivate when subjected to high-end exhaust gas temperature of conventional CI engine operation. Also, their conversion efficiency is severely inhibited by sulphur dioxide resulting from sulphur in fuel. The base metal catalysts are required in a relatively large volume and consequently due to high thermal inertia they took longer to heat up to operating temperature. Therefore in practice only the noble metals are used as they have high specific activity high resistance to thermal degradation, Superior cold start performance and low deactivation caused by fuel sulphur. The noble metals are more expensive but the amount required for an automotive catalytic converter is small about 1 to 2 gm only. The noble metal loading typically varies from about 1.0 to 1.8 g/l (30 to 50 g/ft3) of catalytic converter volume. A mixture of platinum and palladium in 2:1 mass ratio is usually employed as oxidation catalyst. Palladium has higher specific activity than Pt for oxidation of CO, olefins and methane. For the oxidation of aromatics, Pd and Pt have similar activity while for the oxidation of paraffin hydrocarbon (higher than propane) Pt is more active than Pd.

Pellets:- The first catalytic converters of passenger cars in early 1970s used a bed of spherical ceramic pellets. These are also known as packed bed catalytic converter. The spherical pellets made of γ-alumina of 3-6 mm diameter were used. The material of pellets is selected to have a high mechanical strength against crush and abrasion even after exposure to high temperature of around 1000 ^{o}C on the porous surface of pellets that provides a large surface area, the noble metal salts are impregnated to a depth of about 250 µm. The pellets are then dried at about 120 0C and calcined to a temperature of about 500 0C. The pellets catalysts were loaded with approximately 0.05 % by weight of noble metals composed of Pt : Pd in 2.5: 1 mass ratio [1],[2].

Monolith:- A monolith is a ceramic block consisting of a large number of small straight and parallel channels. The monoliths are made by extrusion. A special mixture of clay binders and additives is pushed through a sophisticated dye to create the monolith structure. The material is dried cut to the required length and fired at high temperatures. The monolithic structure has a diameter of about 15 cm and can have different shapes. The diameter of the channels ranges from 0.5 to 10 mm and the length of the monolith can be up to 1 meter long. On the walls of the channels a catalytic active layer can be applied in which chemical reactions can take place. Because of the large number of channels the contact area between the catalytic layer and the fluid that travels inside the channels is very large. The ceramic and metallic monolithic allows high conversion efficiencies at high gaseous throughput, provides a high geometric surface area with lower pressure drop, excellent high temperature and thermal shock resistance and can be conveniently oriented in the exhaust train in any number of directions. The monolithic catalyst is mounted in a stainless steel container with a matting material wrapped around it to ensure resistance to vibration.

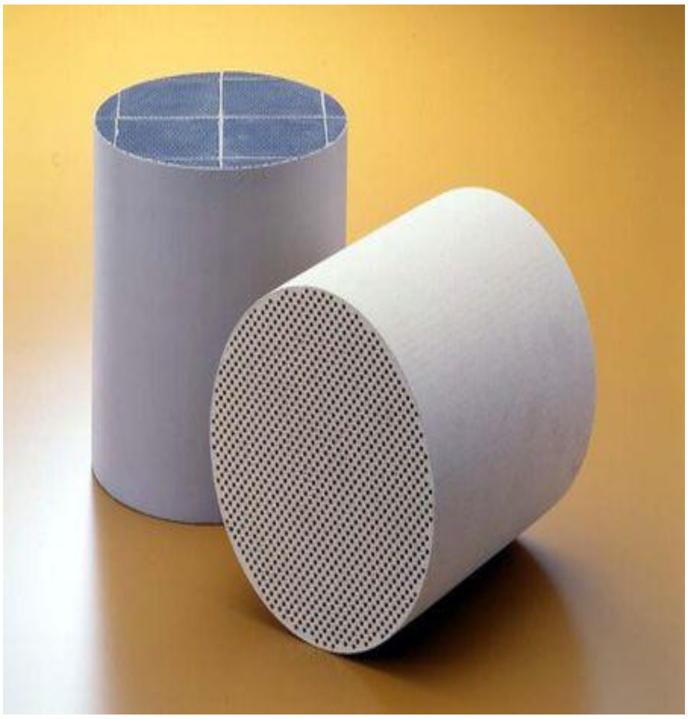
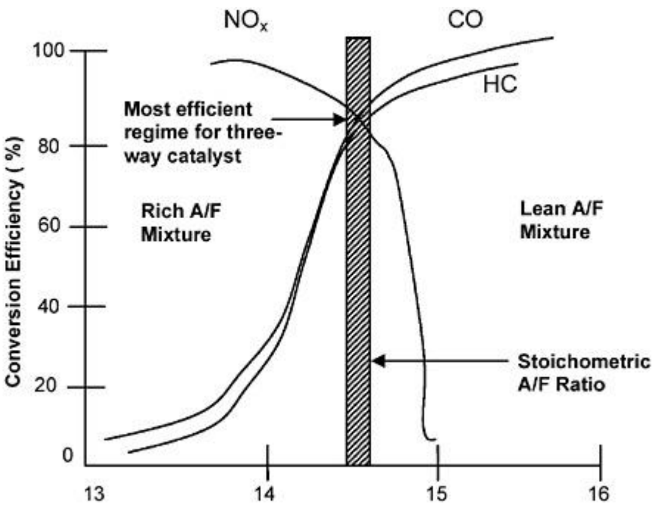


Fig. Monolithic Material

Washcoat:- Ceramic and metallic monoliths have a geometrical surface area of 2.0-4.0 m2 /l of substrate volume. A thin layer of inorganic oxides known as wash coat is applied to the cells in monolith structure to increase effective surface area for dispersion of active catalyst that increase its contact with the reacting gases. The wash coat has pores of varying sizes ranging from 20 to 100 Å. The ceramic monoliths generally have some wall porosity or surface roughness that results in good adhesion of wash coat. The washcoat constitutes about 5 to 15 % of the weight of ceramic monolith. It's thickness typically varies in the range 10-30 µm on the walls and 60-150 µm on the corners of the square cells which reduces the open flow area of the catalyst. Wash coat increase surface area of the catalyst substrate to 10000-40000 m2 /l of monolith volume. The wash coat components support the catalyst function and to improve resistance of catalyst to thermal de-activation processes [3], [4].

Air to fuel ratio:- There is a narrow range of air- fuel ratio near stoichiometry in which high conversion efficiencies for all three pollutants are achieved. The width of this window is narrow about 0.1 air fuel ratio for catalyst with high mileage use and depends on catalyst formulation and engine operating conditions. Conversion efficiency of NO_x, CO and HC as a function of the air-fuel in a three way catalytic converter.



Air-to-Fuel Ra-

Fig. Air to fuel ratio

- When the A/F ratio is richer than stoichiometry: The carbon monoxide content of the exhaust rises and the oxygen content falls. This provided a high efficiency operating environment for the reducing catalyst (rhodium). The oxidizing catalyst maintains its efficiency as stored oxygen is released [4], [5]. A closed loop feedback fuel management system with an oxygen sensor in the exhaust is used for precise control of air-fuel ration. To obtain an efficient control of the A/F ratio the amount of air is measured and the fuel injection is controlled by a computerized system which uses an oxygen (λ) sensor located at the inlet of the catalytic converter. The signal from this λ sensor is used as a feedback for the fuel and air injection control loop. A second λ sensor is mounted at the outlet of the catalytic converter.

This configuration constitutes the basis of the so-called engine onboard diagnostics (OBD). By comparing the oxygen concentration before and after the catalyst, A/F fluctuations are detected.

- When the A/F ratio is leaner than stoichiometry: The oxygen content of the exhaust stream rises and the carbon monoxide content falls. This provides a high efficiency operating environment for the oxidizing catalysts (platinum and palladium). During this lean cycle the catalyst (by using cerium) also stores excess oxygen which will be released to promote better oxidation during the rich cycle.

- ACHIEVEMENTS OF CATALYTIC CONVERTOR:- Today's automobiles are meeting emission standards that require reductions of up to 99 percent for HC, CO and NOx compared to the uncontrolled levels of automobiles sold in the 1960s. Catalytic converters have also been developed for use on trucks, buses and motorcycles as well as on construction equipment lawn and garden equipment marine engines and other non-road engines. Catalytic converters are also used to reduce emissions from alternative fuel vehicles powered by natural gas, methanol, ethanol and propane. To date more than 500 million vehicles equipped with catalytic converters have been sold worldwide. After 2005, 100 percent of new cars sold in the India were equipped with a catalytic converter, and worldwide over 90 percent of new cars sold had a catalyst. It reduces emissions upto 90%. Fuel consumption increases upto 2-3%.

III. LIMITATIONS

In the exhaust stream with temperatures up to 1000 °C. The metal in the catalyst is prone to deactivation by sintering, leading to a reduction in surface area and hence catalytic activity. The conventional means to meet tightening legislative emissions control targets is simply to increase the amount of PGM in the auto catalyst. The need to guarantee catalyst performance over the typical vehicle lifetime of 80,000 km also means that excess metal must be added, since the performance of the catalyst drops off over time. In addition rising PGM demand and costs are incentives towards achieving lower metal loadings and higher activity.

IV. CONCLUSION

Now a day advanced automobiles are designed according to EURO norms. Hence forth they are emitting lesser emissions than the automobiles back in 1960's and below years. Environmental, ecological and health concern result in increasingly stringent emissions regulations of pollutant emissions from vehicle engines. Among all the types of technologies developed so far, use of Metal Monolith type catalytic converters is the best way to control auto exhaust emission. Three-way catalyst with stoichiometric engine control systems remain the state of art method for simultaneously controlling hydrocarbon, CO and NO_x emissions from vehicle. The economical reasons, limited resources of platinum group (noble) metal and some operating limitations of platinum group metal based catalytic converters have motivated the investigation of alternative catalyst materials. This type of Catalytic converters have also been developed for use on trucks, buses and motorcycles as well as on construction equipment lawn and garden equipment marine engines and other non-road engines. Catalytic converters are also used to reduce emissions from alternative fuel vehicles powered by natural gas, methanol, ethanol and propane. To date more than 500 million vehicles equipped with catalytic converters have been sold worldwide.

Acronyms & Abbreviations:-

- TWC Three way catalytic convertor
- Rh Rhodium
- Pt Platinum
- Pd Palladium
- CO Carbon monoxide
- HC Hydrocarbons
- NOx Nitrogen oxides
- PM Particulates matter
- A/F Air to fuel ratio

REFRENCES

[1] H. He, H. Dai and C. Au, "An investigation on the utilization of PerovskitetypeoxidesLa1-xSrxMO3 (M=Co0:77Bi0:20Pd0:03) as three way catalyst", Applied Catalysis B:Environmental, vol. 33, pp. 65-80, 2001.

[2] http://wiki.ask.com/Catalytic_converter

[3] www.fordscorpio.co.uk/cats.html

[4] http://herkules.oulu.fi/isbn9514269543/html/c299.html

[5] N. De Nevers, Air Pollution Control Engineering, McGraw Hill, Chapter,13,pp. 471-510.

[6] Marsh, P., Acke, F., et al., 2001, "Application Guidelineto Define Catalyst Layout for Maximum Catalytic Efficiency", SAE Paper 2001-01-0929.

[7] http://www.cleanairnet.org/baq2004/1527/articles-59196_Kisku.doc

[8] R. Heck, and R. Farrauto, Automobile exhaust catalysts, Applied Catalysis A: General, vol. 221, pp.443-457, 2001.

[9] P. Pundir, Engine emissions pollutant Formation and Advances in Control Technology, Narosa Publishing house, New Delhi, Chapter 1, pp. 1-10.

[10] K. Wark, G. Warner, and W. Davis, Air Pollution and its control, 3rd edition, Wesley Longmann., Chapter 10, pp. 489.

[11] Roy M. Harrison, Pollution causes, effects & control, 2nd edition,
The Royal Society of Chemistry, pp. 221.

