

Review Paper on Catalytic Converter for Automobile Exhaust Emission

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Abstract: The purpose of this paper is to present Air Pollution generated from the Automobile sources has become a big problem and going to become larger as Vehicle population is projected to grow close to 1300 million by the year 2030. There are a number of incomplete combustion products i.e. CO, HC, NOx etc. due to incomplete combustion in engine. These pollutants have negative effects on air quality, environment, and human health as well. To reduce the harmful emission numbers of techniques like improvement in engine design, fuel pre-treatment, fuel additives, and better tuning of combustion process etc. are being considered to minimize the emission of pollutants. Use of Catalytic Converter was found the best way to control the automotive exhaust emission among all of technologies. This Review Paper deals with the automotive exhaust emission and its effects, automotive exhaust emission control by use of catalytic converters, catalysts used in catalytic converter, construction of catalytic converters, types of catalytic converters, working of conventional catalytic converters.

Keywords: Catalytic Converter, Automotive exhaust emission, Pt, Pd, Rh, CO₂, H₂O, O₂, NO_x

1. Introduction

Air pollution generated from mobile sources such as automobiles contributes major air quality problems in rural as well as in urban and industrial areas in both developed and developing countries.



Figure 1: Most polluted cities of Asia

Vehicle population is projected to grow close to 1300 million by the year 2030. A large amount of vehicle transportation relies on combustion of diesel, gasoline, jet fuels with large amount of emission of carbon monoxide (CO), Unburned hydrocarbons (HC), Nitrogen oxide (NO_x) and particulate matters (PM) are specially concern. HC, CO occur because the combustion efficiency < 100%. The NO_x is formed during the very high temperatures (>1500 C) of the combustion process resulting in thermal fixation of nitrogen in the air which forms NO_x. Typical exhaust gases composition at the normal engine operating conditions are: Carbon monoxide (CO, 0.5 Vol. %), unburned Hydrocarbon (HC, 350vppm), Nitrogen Oxides (NO_x, 900ppm), Hydrogen (H₂, 0.17vol. %), Water (H₂O, 10 vol. %), Carbon dioxide (CO₂, 10 vol. %), Oxygen (O₂, 0.5 vol. %). Carbon monoxide is noted poison that has an affinity for Hemoglobin in the blood 210 times more than the Oxygen. The reduction of toxic substances emission from the combustion can be seen in the form of two measures: [1]. Primary measures (Inside Engine): Here many different technical methods are used to reduce the exhaust emission i.e. Combustion of lean air fuel mixture, Exhaust gas

recirculation etc. [2]. Secondary measures (Outside Cylinder): After the primary measures are used, there is an oxidation, reduction, and 3 way catalytic converter based on adsorption procedure. This enables the reduction of CO, HC, And NO_x, that is Desirable.

2. Catalytic Converter

A Catalytic Converter is an emissions control device that converts Toxic gases and Pollutants in exhaust gases to less Toxic pollutants by catalyzing a Redox reaction (an oxidation and a reduction reaction). Catalytic converters are used with Internal Combustion Engine fueled by either petrol (Gasoline) or Diesel- including lean burn engines as well as Kerosene Heaters and Stoves.

2.1 Position of Catalytic Converter Vehicle

The Catalytic Converter is placed inside the tail pipe through which deadly exhaust gases containing unburnt fuel, CO, NO_x etc. are emitted.

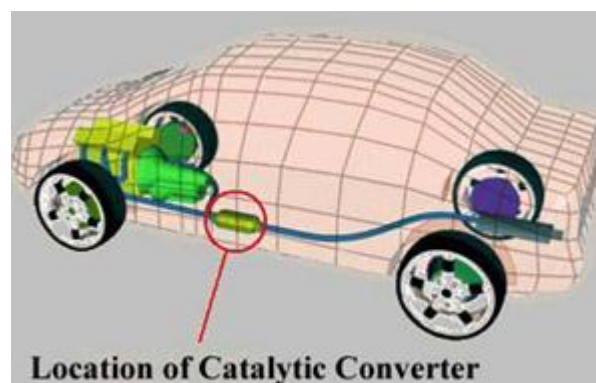


Figure 2: Position of catalytic converter in a vehicle

2.2 Working of Catalytic Converter

The function of the Catalytic Converter is to convert the pollutants into CO₂, Water, N₂, O₂, These are less harmful gases. A mixture of residual quantity of HC, CO, NO_x are

left over after combustion, consequently, a Catalytic Converter uses precious metal like - Platinum (PT), Palladium (PD) as a catalyst to convert harmful pollutants into less harmful gases like- CO₂, O₂, H₂O etc.

Although catalytic converters are most commonly applied to exhaust systems in automobiles, they are also used on electrical generators, forklifts, mining equipment, trucks, buses, locomotives and motorcycles. They are also used on some wood stoves to control emissions. This is usually in response to government regulation, either through direct environmental regulation or through health and safety regulations.

3. History of Catalytic Converters

The catalytic converter was invented by Eugene Houdry, a French mechanical engineer and expert in catalytic oil refining, who moved to the United States in 1930. When the results of early studies of smog in Los Angeles were published, Houdry became concerned about the role of smoke stack exhaust and automobile exhaust in air pollution and founded a company called Oxy-Catalyst. Houdry first developed catalytic converters for smoke stacks called "cats" for short, and later developed catalytic converters for warehouse forklifts that used low grade, unleaded gasoline.[7] In the mid-1950s, he began research to develop catalytic converters for gasoline engines used on cars. He was awarded United States Patent 2,742,437 for his work. Widespread adoption of catalytic converters did not occur until more stringent emission control regulations forced the removal of the anti-knock agent tetraethyl lead from most types of gasoline. Lead is a "catalyst poison" and would effectively disable a catalytic converter by forming a coating on the catalyst's surface. Catalytic converters were further developed by a series of engineers including John J. Mooney and Carl D. Keith at the Engelhard Corporation,[10] creating the first production catalytic converter in 1973. William C. Pfefferle developed a catalytic combustor for gas turbines in the early 1970s, allowing combustion without significant formation of nitrogen oxides and carbon monoxide.[12]

4. Construction

The Construction of a Catalytic Converter can be seen in terms of its basic parts as following:

4.1 Substrate

For automotive catalytic converters, the core is usually a ceramic monolith with a honeycomb structure. Metallic foil monoliths made of Kanthal (FeCrAl)[14] are used in applications where particularly high heat resistance is required. [14] Either material is designed to provide a large surface area

4.2 The Wash coat

A wash coat is a carrier for catalytic materials and used to disperse the material over a large surface area. Aluminum oxide, Titanium oxide, Silicon dioxide, or a mixture of silica and alumina can be used. Catalytic materials are suspended in wash coat prior to applying to the core. The coat must

retain its surface area and prevent sintering of the Catalytic metal particles even at the high temperature (1000 C).

4.3 Ceria

These oxides are mainly added as oxygen storage promoters.



Figure 3: Ceramic- Core converter

5. Types of Catalytic Converter

Generally catalytic converter are classified into two categories-

5.1 Two –Way

A 2-way (or "oxidation", sometimes called an "oxi-cat") catalytic converter has two simultaneous tasks:

1. Oxidation of carbon monoxide to carbon dioxide: $2CO + O_2 \rightarrow 2CO_2$
2. Oxidation of hydrocarbons (unburned and partially burned fuel) to carbon dioxide and water: $C_xH_{2x+2} + [(3x+1)/2] O_2 \rightarrow xCO_2 + (x+1) H_2O$ (a combustion reaction)

This type of catalytic converter is widely used on diesel engines to reduce hydrocarbon and carbon monoxide emissions. They were also used on gasoline engines in American- and Canadian-market automobiles until 1981. Because of their inability to control oxides of nitrogen, they were superseded by three-way converters.

5.2 Three – way

Three-way catalytic converters (TWC) have the additional advantage of controlling the emission of nitric oxide and nitrogen dioxide (both together abbreviated with NO_x and not to be confused with nitrous oxide), which are precursors to acid rain and smog. Since 1981, "three-way" (oxidation-reduction) catalytic converters have been used in vehicle emission control systems in the United States and Canada; many other countries have also adopted stringent vehicle emission regulations that in effect require three-way converters on gasoline-powered vehicles. The reduction and oxidation catalysts are typically contained in a common housing; however, in some instances, they may be housed separately. A three-way catalytic converter has three simultaneous tasks:

- 1) Reduction of nitrogen oxides to nitrogen and oxygen:
 $2NO_x \rightarrow xO_2 + N_2$

- 2) Oxidation of carbon monoxide to carbon dioxide: $2CO + O_2 \rightarrow 2C$
- 3) Oxidation of unburnt hydrocarbons (HC) to carbon dioxide and water: $C_xH_{2x+2} + [(3x+1)/2] O_2 \rightarrow xCO_2 + (x+1)H_2O$.

These three reactions occur most efficiently when the catalytic converter receives exhaust from an engine running slightly above the stoichiometric point. For gasoline combustion. This ratio is between 14.6 and 14.8 parts air to one part fuel, by weight



Figure 4: A three way catalytic converter

5.3 Comparison between Two-way and Three-way catalytic converter:

Three ways catalytic converter are better than the two ways in terms of efficiency and effectiveness as we can see from the following chart

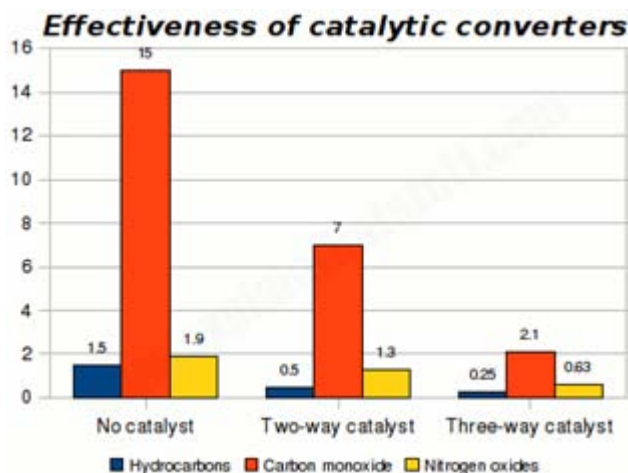


Figure 5: Effectiveness of catalytic converters

4. Conventional Catalytic Converter

A conventional catalytic converter is a ceramic block, which is honeycombed with microscopic channels that are coated in a rare metal such as platinum.. Emissions travel from the engine to the exhaust system and through the channels, where the precious metal causes a chemical reaction to occur

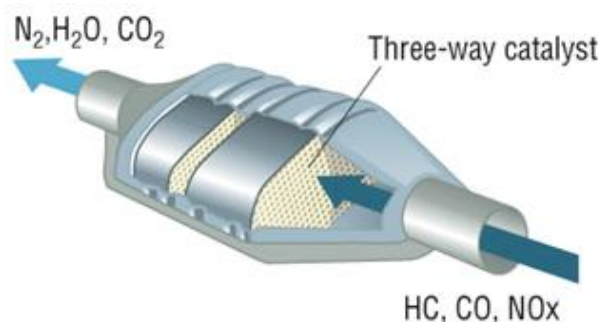
that eliminates the harmful pollutants. The researchers have advanced an existing manufacturing process to improve the structure of the microscopic channels, increasing the surface area and enabling the rare metal in the device to be distributed more effectively so that less metal is used. The increased surface area also makes the catalytic converter's chemical reaction process more efficient.

Figure 6: A Conventional three way catalytic converter

6. Catalysts used in Catalytic Converters

There are mainly three catalysts that are used in a catalytic converter -

- [1] Palladium (pd)- It is used in Oxidation Reactions [2]
- Rhodium (Rh) – It is used in Reduction Reactions [3]
- Platinum (pt.) – It is used in both Oxidation and Reduction Reactions as well.



7. Conclusion

Today's automobiles are meeting emission standards that require reductions of up to 99% of HC, CO and NOx compared to the uncontrolled levels of automobiles sold in the 1960s. Environmental, Ecological and Health concern result in increasingly stringent emissions regulations of pollutant emissions from vehicle engines. Use of metal monolith type catalytic converters are the best way to control the auto exhaust emissions. The economic reasons, limited resources of platinum group (Noble Group) metal and some operating limitations of platinum group metal based catalytic converters have motivated towards the investigation of alternative catalyst materials. This type of catalytic converters have also been developed for the use on trucks, buses and motorcycles as well as on construction equipment lawn and garden equipment etc. In 2005, 100% of the new cars sold in the U.S. were equipped with a catalytic converter , and Worldwide over 90% of the new cars sold had a metal monolith type Catalyst.

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Prashant Katara is pursuing his B. Tech in Mechanical Engineering from NIT Raipur and presently studying in his third year of under graduation (2014-2018). His field of interest is Automobile, Sustainable Energy and Classical Physics. He is an active member of SAE NIT RAIPUR (Present).