Experimental Investigation of Three-Way Catalytic Convertor Based on Cerium and Titanium in C.I Engine

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Abstract: ***This project presents the characteristics of a new catalytic converter to be used for diesel fuelled engine. Two types of catalytic converters were developed to reduce emission effectively with low cost which is based upon the catalyst material. The metal oxide such as titanium dioxide (TiO_2), cerium oxide (CeO_2), copper nitrate ($Cu(NO_3)_2$), and Zirconium dioxide (ZiO_2) with wire mesh substrate were used. Both the catalyst material used in these catalytic convertors are inexpensive in comparison with conventional catalyst made up of nobal metals such as Platinum (Pt), Palladium (Pd) and Rhodium (Rh) which are currently in use. The nobal metals are identified as human health risk due to their rapid emissions in the environment. The Original Equipment Manufacture Catalytic Converter was tested for comparison purposes. The OEM catalytic converter was based on noble metal catalyst with honey comb ceramic substrate. The objective of this project is to develop a cost effective three way catalytic converter to be used in diesel fuelled engine. Detailed review on cost effectiveness, reduction of emission of new catalytic converter in diesel fuelled engine and test results have been reported with discussions.***

Keywords: Catalytic converter, Exhaust emission, emission test, pollution control

1. Introduction

Automobiles are 'necessary evil', while they have made to live easy and convenient. Automobile plays most important role in human life. They have also made human life more complicated and vulnerable to both toxic emission and an increased risk of accidents. Because of the carelessness and Natural force these problem will developed in the automobile .The incomplete combustion in the engine, can develop number of incomplete combustion product CO, HC, NOx, particulate matters etc.

The major reason for the incomplete combustion is cold condition start problem, uncleaned fuel and heavy vehicle hill claiming, etc. These pollutants have negative impact on air quality as well as on human health also on environment that leads in stringent norms of pollutant emission. Number of alternative technologies like improvement in engine design, fuel pre-treatment, use of alternative fuels, exhaust treatments etc, to reduce the emission level of engine. Among all the types of technologies developed so far, use of catalytic converter is the best way to control automotive exhaust emissions.

Exhaust pollutants from the automobiles engine have negative impacts on air quality as well as on human health. In previous section we have studied how emission are produced by an automobile and effect of automobile exhaust emission on human as well as on environment and also discussed about exhaust emission control techniques. The catalytic converter only reduce pollution effectively with number of catalyst material. The catalyst materials are the chemicals which is directly react with the exhaust of the engine. So, the pollutants were converted into harmless gases of atmosphere. But also there are some inefficiency of the converter like poisoning, fracture, melting and higher cost.

To reduce that the Current study focuses on new developed catalytic converter. The objective of this paper is to develop cost effective catalytic converter to be used with petrol and diesel fuelled engine. The inexpensive catalytic converter development, performance evolution and engine test results have been presented with discussion.

2. Evolution of Catalytic Converters

Catalytic converter has gone through many processes and remarkable evolution for the past 30 years. It is said to be one of the most effective tool to fight against the overwhelming pollutant contents in our environment, as it reduces almost 80% of the harmful gases resulting from the incomplete combustion of the engine. Catalytic converter is a stainless steel container mounted somewhere along the exhaust pipe of the engine and inside the container is a porous ceramic structure through which the exhaust gas flows (Ganesan, 2004). In most converters, the ceramic is a single honeycomb structure with many flow passages. The passages comprise of many shapes, including square, triangular, hexagonal and sinusoidal. Early converters used loose granular ceramic with the gas passing between the packed spheres. Since it is difficult to keep the spheres in place, many converter developers opted for ceramic monolith which offers various advantages. Among these advantages are smaller volumes, lower mass and greater ease of packaging (Heck & Farrauto, 1995).

The active catalyst layer is applied on the monolith walls. The coating, called 'washcoat', is composed of porous, high surface area inorganic oxides such as γ-Al_2O_3 (gamma alumina), CeO_2 (Ceria) and ZrO_2 (Zirconia). Noble metal catalysts, such as Platinum (Pt), Palladium (Pd) and Rhodium (Rh), are deposited on the surface and within the pores of the wash coat (Pontikakis, 2003). Exhaust gas flowing in a catalytic converter diffuses through the wash coat pore structure to the catalytic sites where heterogeneous catalytic reactions occur. The washcoat layer on metallic foil and on ceramic substrate is illustrated in Figure 1. The thickness of the washcoat layer is typically 20-100 µm. Much thicker washcoat deposits ("fillets") are formed in the cell corners, especially in the sinusoidal channels of metallic substrates. Automotive industry for carbon monoxide and hydrocarbon oxidation. Reduction of noxious gas (NO_x) was relaxed, until 1979 where TWCC began to be implemented in automotive exhaust systems of majority vehicle models (Heck & Farrauto, 1995). TWCC provides both oxidation and reduction processes to replace two-way converter and generally, the CO reaction begins first, followed by the HC and NO_x reactions. With lean-mixture conditions the catalyst promotes the complete oxidation of HC and CO:

$2CO + O_2 \rightarrow 2CO_2$

$4HC + 5O_2 \rightarrow 4CO_2 + 2H_2O$

With rich-mixture operation, the catalyst promotes the reduction of NO_x by reactions involving HC and CO:

$2CO + 2NO \rightarrow 2CO_2 + N_2$

$4HC + 10NO \rightarrow 4CO_2 + 2H_2O + 5N_2$

When TWCC is used, it requires an engine management system capable of very accurate air/fuel ratio control, and a catalyst. Actually, the emissions of CO, NO_x and HC vary between different engines and are dependent on such variables as ignition timing, load, speed and, in particular, fuel/air ratio.

Latest works and research papers emphasized more on predicting the performance of catalytic converter in an early design stage, rather than setting up an experiment or laboratory test bench. Joachim Braun *et. al* (2002) mentioned that for the three-way catalyst, the major concern is the correct prediction of light-off behavior of the exhaust system. By modelling a converter with proper dimensions and its related properties, it is possible to see the situation that happens during the complicated chemical processes. In order to achieve reliable results, the numerical simulations have to be based on accurate models of all the significant chemical and physical processes in the catalytic converter.

The latest computational fluid dynamics (CFD) software utilized in the catalytic converter analysis is the newly developed DETCHEM^{MONOLITH}, acronym of 'Detailed Chemistry' used for the numerical simulation of the transient behavior of the TWCC. The code combines the two-dimensional simulations of the reactive flows in a representative number of monolith channels with a transient simulation with the three-dimensional temperature field of the solid structure of the converter including insulation and canning (Braun *et. al*, 2002). The chemical reactions are modelled by a multi-step heterogeneous reaction mechanism, which is based on the elementary processes on the platinum and rhodium catalysts used.

FLUENT is also CFD software used for the same purpose. The model is constructed and meshed first in GAMBIT, a drafting program bundled with FLUENT and the finished model is then exported to FLUENT for further analysis. Catalytic converter substrate is defined as a porous media in FLUENT, where viscous and inertial losses are specified in both the stream wise and transverse directions. By using the porous media model, the number of cells in the computational mesh can be reduced significantly, since the small geometric details of the substrate do not need to be resolved. Apart from simulating flow in catalytic converter, another method to optimize the converter performance is through the geometry modification and analysis. Substrate geometries have a great influence in catalytic activity as well as the flow pattern in the channel. The cell shape influences some parameters such Several research works and publications agreed that the manipulation of converter geometries at design stage have led to channel optimization without spending much on new fabrications.

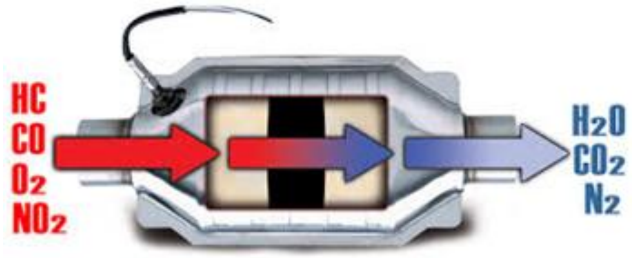

Figure 1.1: Basic catalytic converter

Types of Catalytic Converter

There are two important types of catalytic converter,

1) Two-way catalytic converter. (Oxidation)
2) Three-way catalytic converter. (Oxidation and Reduction)

Objective

Nowadays, pollution is a major concern in which most of the pollution is through the exhaust of engines. Even though the latest development of catalytic converter reduces the exhaust emission, the emission is still in the increased rate. This is due excessive usage of automotives in the day today world. After development most the emission is controlled by catalytic converter but the catalysts costs, more due to usage of platinum which is one the catalyst in converter. Our primary objective is to control the emission effectively with new catalytic substances such as Copper Nitrate, Cerium Dioxide and Titanium Dioxide. Secondary objective is to reduce the overall cost of the converter. Since the platinum has high value in the market many catalytic converter has theft from the cars. Since our catalytic converter consists chemical catalyst which lowers its price for instance we can make 4 converters at the cost one present converter

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New Catalytic Converter Generation

The new catalytic converter can be developed based on the catalyst used in the converter. We are changing the catalyst in the existing catalytic converter to reduce the pollution and cost of the converter. The currently used catalyst are Platinum, Rhodium and Palladium these are very high cost catalyst. So, the cost of the catalytic converter also very high. In our project catalyst are very less cost and pollution control efficiency also better when compare to the existing catalyst. We are fabricating two type of catalytic converter based on the catalyst preparation or used in the converter. We are using the wire mesh instead of honey comb ceramic duct. The wire mesh is made up of stainless steel. Our catalyst are Titanium Dioxide, Copper Nitrate, Cerium oxide, Zirconium Dioxide .There are two types of converters are prepared,

1) Titanium based catalytic converter:Titanium Dioxide, Copper Nitrate, Zirconium Dioxide.
2) Cerium based catalytic converter:Cerium Oxide, Copper Nitrate, Zirconium Dioxide.

These catalyst are mixed in the magnetic stirrer with distilled water after the slurry preparation the wire mesh are dipped in the slurry and drying in the room temperature itself.And the meshes are heat-treated in the hot air oven for a period of time and then the meshes are assembled and fitted into the converter to get further results. After the assembling the converter are proceeded to the emission testing and the results are compared and documented.

Materials Needed For New Catalytic Converter:
Materials required for fabrication of new catalyst based catalytic converter are as follows,

1) Wire mesh.,
2) Distilled water and Concentrated HCL Acid.
3) Chemical catalyst.

3.1 Titanium Based Converter.
3.1.1 Titanium Dioxide.
3.1.2. Copper Nitrate.
3.1.3. Zirconium Dioxide
3.2 Cerium Based Converter.
3.2.1 Cerium Oxide
3.2.2. Copper Nitrate
3.2.3. Zirconium Dioxide

4) Insulation material

Process flow for Catalytic Converter
1. Titanium based catalytic converter: Titanium Dioxide, Copper Nitrate, Zirconium Dioxide.
2. Cerium based catalytic converter: Cerium Oxide, Copper Nitrate, Zirconium Dioxide.

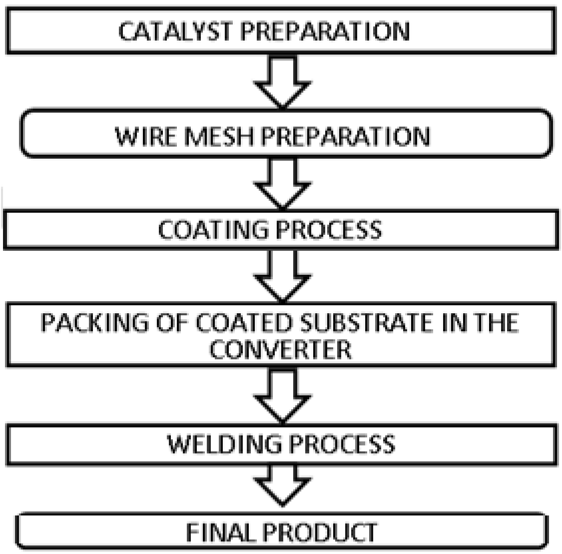

Figure 1.2: Mesh Package or Converter Substrate (titanium based)

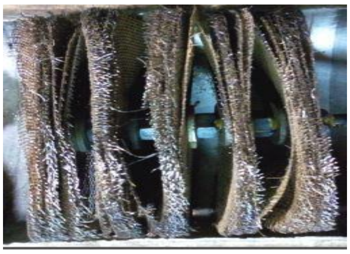

Figure 1.3: Mesh Package or Converter Substrate (cerium based)

Fabricated Catalytic Convertors

Figure 1.4: Titanium Based catalytic Converter

Figure 1.5: Cerium Based Catalytic Converter

The Characteristics of New Catalytic Converter

Table 5.1: Catalytic converter characteristics comparison

S.No	Specification	New Catalytic Converter	OEM Catalytic Converter
1	Substrate Material	Wire Mesh (S.S)	Cordierite-Ceramic
2	Wash Coat	TiO_2, TITANIA	Alumina
3	Catalyst-1	TiO_2 / $Cu(NO_3)_2$	Pt / Pd /Rh
4	Catalyst-2	CeO_2 / $Cu(NO_3)_2$	Pt / Pd /Rh
5	Surface Area	7560	7560
6	Catalyst Volume	1.6	1.6

Emission Testing Characteristics

1) **Without catalytic converter:** Present emission result when no catalytic converter was fitted in the exhaust system.
2) **OEM catalytic converter:** Present emission result when the OEM catalytic converter was fitted on the exhaust system at close to the engine exhaust manifold
3) **Wire mesh catalytic converter $TiO_2/Cu(NO_3)_2/ZrO_2$):** Present emission result when the Titanium based catalytic converter is fitted on the exhaust system and the data were collected from the exit/entrance of wire mesh catalytic converter.
4) **Wire mesh catalytic converter ($CeO_2/Cu(NO_3)_2/ZrO_2$):** Present emission result when Cerium based catalytic converter is fitted on the exhaust system and the data were collected from the exit/entrance of wire mesh catalytic converter.

3. Conclusion

The new catalytic converters are fabricated with chemical catalysts such as copper nitrate, titanium dioxide, zirconium dioxide and cerium dioxide for reduction of emission. Instead of honey comb substrate a stainless steel wire mesh is replaced by carrying the chemical components in it as a catalyst which undergoes the oxidation and reduction processes in order to reduce to toxic gases that pollute the environment. The results revealed that the new type catalytic converters controls the emission about 12% of the emission more than the existing model catalytic converter. This shows that the converters are controlling effectively than present ceramic substrate catalytic converters. These converters are also developed in low cost than the present converter. So that the overall cost of the catalytic converter is reduced, such that we can do 4 converters from single present catalytic converter.

Comparison of Catalytic Converter Emission:

S.NO	Catalytic Converter	K - Value	HSU - Value
1	Without Catalytic converter	Above 2.45	Above 65
2	OEM Catalytic Converter	1.53	47.6
3	Titanium Based Catalytic Converter	1.22	40.82
4	Cerium Based Catalytic Converter	1.32	43.31

4. Scope

The model can be further modified to reduce the emission more than the current work by adding additives of various chemicals in it. It can be modified design wise in order to reduce the sound waves that are produced due to combustion. This could be useful to reduce the noise pollution.

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