A Technical Review of Automobile Catalytic Converter: Current Status and Perspectives

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Abstract: In this Scenario the air pollution generate from the mobile sources are big problem in this world. The maximum quantity of air pollution is due to the emissions from an Internal Combustion Engine. Catalytic combustion of pollutants release form the vehicular exhaust is one of the finest approaches to decrease their attentiveness before their release to the atmosphere. The catalyst helps to bring about the decrease of these pollutants at considerable lower temperatures as parallel to combustion reactions.

In this article a review about the noble metal catalyst and base metal used for gasoline vehicles is carried out. After comparing the noble metal catalyst and base metal catalyst it is concluded that the noble base catalyst are expensive and limited to supply are the best method for the reduction of pollutants carbon monoxide, oxides of nitrogen and hydrocarbons released from the internal combustion engine exhaust.

Keywords: Catalytic Converter; Noble metal; Base metals; Exhaust Emission.

1. INTRODUCTION

The pollutants have undesirable effect on air quality, environment and human health that tips in stringent norms of pollutant emission. Numbers of different technologies like Upgrading in engine design, fuel pre-treatment, use of alternative fuels, fuel flavours, exhaust treatment or superior tuning of the combustion process etc. are being pain taking to reduce the emission levels of the engine. Out of many technologies available for automobile exhaust emission control a catalytic converter is found to the best option to control HC, CO and NO_x emissions from petrol driven vehicles while diesel particulate filter and diesel oxidation catalyst or oxidation catalysts converter have so far been the most potential option to control particulates emissions from diesel driven vehicle.

A catalytic converter is placed inside the tailpipe through which deadly exhaust gases containing HC, CO, NO_x are emitted. The function of the catalytic convertor is to convert these gases into CO_2, H_2O, N_2 and O_2 and currently, it is necessary for all automobiles pursuing on roads.**[16]**

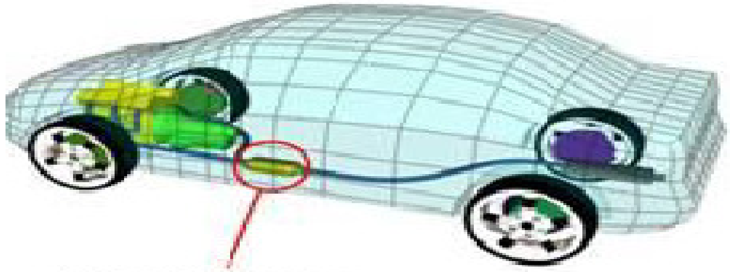

Fig.1: ***Position of Catalytic Converter in Car [17]***

Catalytic Converter is the vehicle control device which is used to convert the toxic by- products of combustion in the exhaust of an internal combustion engine to less toxic product by using catalyst chemical reactions. The role of a catalyst in decrease of pollutants with exhaust impurities is pertinent by the electric control Device (ECD) of the car power train. Mostly the performance of catalyst converter is highly reliant on the type of catalyst used in an assembly. The rate of the chemical reactions is affected by the presence of catalyst. [1] Catalyst acts as a mediator that reduces the activation energy of the reaction of interest, commonly not being transformed during the reactive chain. [2][3].

1.1 Noble Metals

The noble metal is mostly carried out the reactions in the converters. They are also stated to as the valuable metal or platinum group metals. They are preferred as an active catalytic materials in automobiles [4]. Noble Metal have excellent thermal stability, their lower tendency to react with sustenance materials linked to base metals and their ability to process gas streams covering upwards of 1000 (ppm) sulphur without being changed to bulk surfaces [2].The noble metal shows maximum catalytic activity and thus introduced catalytic oxidation of fuels at lowermost temperature these reaction take place on the surface of tiny metal crystals in the catalyst coating [5][6].

Palladium and platinum are chosen over other noble metals for oxidation reactions as related to them all other noble metals display higher volatility due to their high temperatures and high velocities of gases met during exhaust gas treatment which was disagreeable [4][5].

The aspect that primarily lead to their increased use are that only the valuable metals required for the removal of the pollutants in the very short dwelling time verbalized the large volumetric flows of the exhaust in relation to the size of catalyst which could be accommodated in the existing space. The precious metals were the only catalytic materials with the requisite resistance to poisoning by residual amount of sulphur in the exhaust. The precious metal were less disposed to but not entirely resistant to deactivation by high temperature interaction with the insulation oxides of Ce, Al, Or etc., which constitute the so called high surface area “washcoat” on which the active catalytic element are spread. [7]

Initially in the U.S in the years 1975-1980, platinum and palladium remained used as oxidation catalyst in the ratio 5 (Pt): 2 (Pd) at a typical loading of 50-70 g/ft^3. Rhodium introduced with the arrival of three way catalysts, having significantly superior activity that Pt or Pd for the catalytic reduction of the oxides of nitrogen [8].when sufficient Rh is present the participation of Pt in NO removal is minimum [9]. The amount of precious metal loadings are 30-100 g/ft^3 for Pt, 0-120 g/ft^3 for Pd and 5-10 g/ft^3 for Rh. [10].

Table.1: Metal contents of different catalyst loading [10]

Catalyst Type	Loading		Ratio	Individual Metre loading		
	g/l	g/ft^3		Pt	Pd	Rh
Pt: Rh	1.41	40	5:1	1.17	-	0.24
Pt: Pd: Rh	3.35	95	1:14:1	0.21	2.93	0.21
Pd	4.94	100	-	-	4.94	-
Pd: Rh	3.53	100	14:1	-	3.29	0.24

The fuel superiority plays an important role in the choice of catalyst formation for a particular market due to present of residuals Pb level sulphur concentrations. As all of the preparation have recover over time decisions concerning the choice of the noble metal and loading are becoming more and more based on cost factors. In order to decrease the pollution the thickness of the washcoat containing the noble metal has to be increased. But this results in increase of sulphur emission and also the cost of the converter.

1.2 Base Metal

Base metal is metal which is used to refer to a metal that oxidizes or corrodes comparatively easily and reacts variably with diluted hydrochloric acid. The major difficulty of base metal catalyst is that they were found to be very sensitive towards sulphur poisoning;[12] They were also sensitive to thermal degradation at high temperature. The conversion activities of the base metal catalyst were found to be a much fewer as compared to noble metal catalyst. The base metal catalyst required larger converter volume as related to the noble metal catalyst.[11][13].

1.3 Review and Methodology of the Research

It is clear from the objective that there is a need to study the efficiency of the catalytic converter to improve the design of the catalytic converter. The main three ways of evaluation the catalytic efficiency are as follows:

- By evaluation of amount of NOx & CO
- By using Oxygen sensor
- By the use of Temperature Sensors
  -

The evaluation of catalytic efficiency by the use of NOx and CO sensors is also frequent. The exhaust sensors are installed in two places. The one part before the catalyst and the other part after the catalyst, in such a way its effect on the exhaust gas which passed through the catalyst is measured and finally the catalytic efficiency are evaluated.[14]

Calculation of the catalyst efficiency by use of oxygen sensors lambda sounds Exhaust Gas Oxygen sensor [EGO], Universal air to fuel ratio Exhaust Gas Oxygen sensor [UGOS], Heated Exhaust Gas Oxygen sensor (HEGO) is quite common. Connection of a diagnostic device to the engine's on Board Diagnostics [OBD II] connector enables indication and recording the sensors indications as well as indications of all other sensors of the car under test. The oxygen sensors are installed one before and another after the catalyst. So the quantity of oxygen in the engine exhaust is dignified before and after the catalyst, and the results of the measurements describe the superiority of the catalyst.[15]

The third method to calculate the efficiency is temperature measurement. Because of the measurement easiness temperature was measured on the outer surface of the exhaust pipe, not inside the pipe.

$$\Delta T = T2 - T1 \qquad \text{(i)}$$

Where T1 = Temperature of the exhaust pipe before the catalytic converter in °C

T2 = Temperature of the exhaust pipe after the catalytic converter in °C

1.4 Types of Catalytic converter

1.4.1 The Oxidization Catalytic Converter

An oxidation catalyst is an expedient placed on the tailpipe of a car. The oxidation catalyst is the second stage of the catalytic converter. It decreases the unburned hydrocarbons and carbon monoxide by burning them over a platinum and palladium catalyst. This catalyst aids the reaction of the CO and hydrocarbons with the remaining oxygen in the exhaust gas. [18][19]

$HC + O_2 = CO2 + H_2O$ (ii)

$2CO + O_2 = CO_2$ (iii)

1.4.2 The Reduction Catalytic Converter

A reduction catalyst to control NOx can be used as a distinct system in addition to the oxidation catalytic converter. The reduction catalyst is the first stage of the catalytic converter. It uses platinum and rhodium to decrease the nitrogen oxide emissions. When such molecules come in contact with the catalyst, the catalyst rips the nitrogen atom out of the molecule and holds on to it, freeing the oxygen in the form of O_2. The nitrogen atoms bond with other nitrogen atoms that are also stuck to the catalyst forming N_2. [20]

$2NO = N_2 + O_2$ (iv)

1.4.3 The Three Way Catalytic Converter (TWCs)

TWCs have the benefit of performing the oxidation of carbon monoxide (CO), hydrocarbons (HC) and the reduction of nitrogen oxides (NOx) simultaneously. Noble metals are usually used as the active phase in TWCs. Pd catalysts are especially attractive since Pd is by far the inexpensive noble metal in the market and has well selectivity and activity for hydrocarbons. Rhodium the other vital constituent of three-way catalysts is broadly recognized as the most efficient catalyst for promoting the reduction of NO to N_2. The TWCs performance in the emission control can be affected by operating the catalyst at elevated temperatures greater than 600°C.

The major reactions are the oxidation of CO and HC and the reduction of NOx. Also, water gas shift and steam reforming reaction occur. Intermediate products such as N_2O and NO_2 are also originated. The NOx storing concept is based on combination of a storage component into the three-way catalyst (TWCs) to store NOx during lean conditions for a time period of minutes. [18]

Reaction in the Catalytic Converter

$2CO + O2 = 2CO2$ (v)
Oxidation $HC + O_2 = CO_2 + H_2O$ (vi)
Reduction/ Three way $2CO + 2NO = 2CO_2 + N_2$ (vii)
$HC + NO = CO_2 + H_2O + N_2 + 2H_2$ (viii)
$2NO = 2H_2O + N_2$
Water Gas Shift $CO + H_2O = CO_2 + H_2$ (ix)
Steam Reforming $HC + H_2O = CO_2 + H_2$ (x)

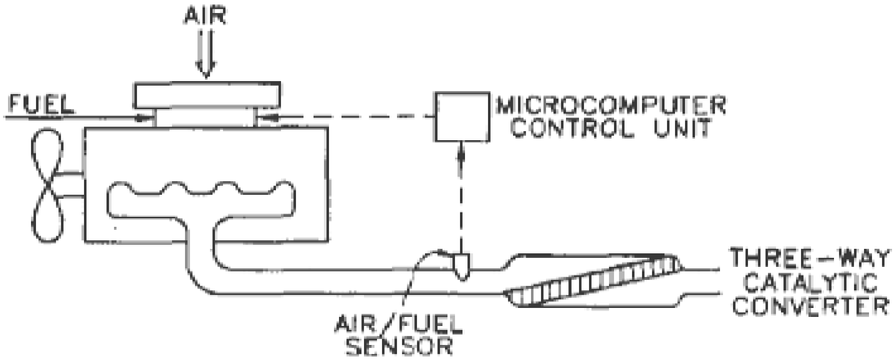

Fig.2: ***Schematic Diagram of Three Way Catalytic Converter***

1. AIR TO FUEL RATIO

The figure shows the conversion efficiency of CO, NO and HC as a function of A/F ratio in a three way Catalytic Converter. In this figure it shows the conversion efficiency of NO, HC and CO as a function of A/F ratio. There is a fine range of air- fuel ratio near stoichiometry in which high conversion efficiencies for all three pollutants are attained. The width of this window is narrow about 0.1 air-fuel ratio for catalyst with high mileage use and be contingent on catalyst formulation and engine working conditions.

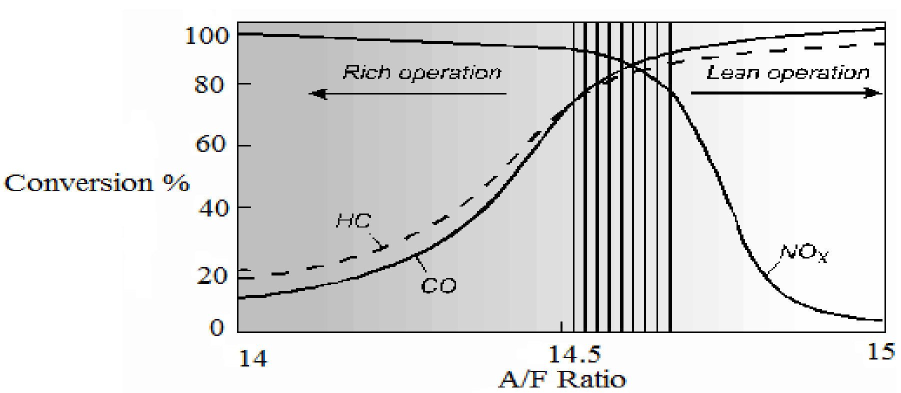

Fig.3: ***A/F Ratio [21]***

2.1 When the A/F ratio is leaner than Stoichiometry

The oxygen content of an exhaust stream increases and the carbon monoxide content falls. This delivers a high efficiency operating environment for the oxidizing catalysts (platinum and palladium). During this lean cycle the catalyst (by using cerium) also stores extra oxygen which will be released to promote superior oxidation during the rich cycle.

2.2 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. [20][21]

A closed loop feedback fuel management system with an oxygen sensor in the exhaust is used for specific control of A/F ratio. To getawell-organized 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 situated 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 equestrian at the outlet of the catalytic converter. This configuration establishes the basis of the so-called engine on-board diagnostics (OBD). By linking the oxygen concentration before and after the catalyst, A/F fluctuations are noticed. Extensive fluctuations of A/F at the outlet signal system failure. Effect of A/F ratio on the conversion efficiency of three-way catalysts narrow A/F window at the stoichiometric point is the impression of an effective TWC system.

2. LIMITATION OF CATALYTIC CONVERTER

In the severe situations experienced in the exhaust stream with temperatures up to 1000 °C the metal in the catalyst is disposed to to deactivation by sintering, leading to a decrease in surface area and hence catalytic activity. The conventional means to meet constriction legislative emissions control goals is simply to increase the amount of PGM in the auto catalyst. The requirement to guarantee catalyst performance over the distinctive 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 request and costs are inducements towards attaining lower metal loadings and higher activity. [22]The compounds of the PGM are generally considered highly toxic while the Pd and Rh are carcinogenic in nature. Due to the fact that the PGM are created due to the scrape of an automotive catalyst washcoat. That is why the road traffic is responsible for metallic and organic pollutant – emissions which contaminate the environment. [23] The catalytic converters in the exhaust system developworsened by several mechanisms e.g. thermal deterioration and poisoning. Thermal deterioration occurs as a result of contact of the catalyst to high temperature conditions. This cause sintering of the PGM, loss of provision surface area and phase transformation. Poison also cause loss of activity mainly by obstructive the pores leading to active sites or even by direct impasse of the active sites themselves. [24][25]

3. CONCLUSION

With almost all the current investigation on catalytic converters, it is possible to predict a day where automobiles are no longer identified to pollute and harm the environment. Today's automobiles are meeting emission standards thatneed to reduce of up to 99 percent for CO, Unburned Hydrocarbons and NOx compared to the unrestrained levels of automobiles sold in the 1960s.

Three-way catalyst (TWCs) with stoichiometric engine control systems endures the state of art technique for concurrently controlling hydrocarbon, CO and NOx emissions from automobiles.The financial reasons, limited capitals of platinum group noble metal and some working limitations of platinum group metal based catalytic converters have driven the study of alternative catalyst materials.

REFERENCES

[1] Pukalskas Saugirdas., Zautra Rytis., Nagurnas Saulius., Matijosius Jonas., Svelnia Virginijus., Vegneris Recardas., Zuraulis Vidas., Juknelevicius Romualdas.,(2013), Research of Efficiency of Catalytic Converters in Automobiles with an Otto Engine, Transport Engineering Faculty of VGTU 8th National Conference, ISSN: 2029-2384 vilnius, Lithuania.

[2] Jobson E., Laurell M., Hogberg E., Bernler H., Lungren S., Wirmak G., Smedler G.,(1993),*SAE Paper 9309*37, Pg. 639- 652.

[3] Sinfelt J.H., (2002) Surface Science 500,Pg. 923-946.

[4] Choudhary T.V., Banerjee S., Choudhary V.R, (2002), Applied Catalysts A*: General,* 234, Page 1-23.

[5] Arai H., Machida M., (1991), Catalysis Today, 10, Pg. 81-94.

[6] Cooper B.J., (2002),Commemorative Lecture at the Twenty-Third Honda Prize Awarding Ceremony, Tokyo.

[7] Shelef M., McCabe R.W., (2000) Catalysis Today, 62, Pg. 35-50.

[8] Muraki H., Sobukausa M., Kimura M., Isogai A.,(1990) SAE Paper No. 900610,

[9] Koltsakis G.C., Stamatelos A.M., (1997) Programme Energy Combustion Science, Vol. 23, Pg. 1-39.

[10] Brisley R.J., Chandler G.R., Jones H.R., Anderson P.J., Shady P.J., (1995)SAE Paper No. 950259, Pg. 317- 329.

[11] Gandhi H.S., Graham G.W., Mckabe K.W., (2003), Journal of Catalyst,216, Pg. 433-442

[12] Gandhi H.S., Williamson W.B., Bomback J.L., (1982), Applied Catalysis,Vol 3, Pg.79-88.

[13] Choudhary T.V., Banerjee S., Choudhary V.R., (2002), Applied Catalysts A: General, 234, Pg. 1-23.

[14] Kumara P., Makkic I., Kernsc J., Grigoriadisb K., Franchekb M., Balako-taiaha V., (2012), A low-dimensional model for describing the oxygen storage capacity and transient behavior of a three-way catalytic converter, Chemical Engineering Science 73, Pg. 373–387.

[15] Balenovic M., Edwards J., Backx T., (2006), Vehicle application of model-based catalyst control, Control Engineering Practice 14(3),223–233, ISSN 0967-0661.

[16] Patel Bharat S., Patel Kuldeep D., (2012), A review paper on Catalytic Converter on Automobile Exhaust Emission, International Journal of Applied Science Research, ISSN 0973-4562, Vol. 7 No. 11

[17] Shelef M., McCabe R.W., (2000), Twenty five years after introduction of Automobile Catalyst: What next? Catalyst Today, Vol, 62, Pg. 35-50.

[18] Bera A., Hegde M.S., (2010), recent advances in auto exhaust catalysis, Journal of the Indian Institute of Science, Vol. 90:2, pg.299-325.

[19] Heck R., Farrauto R., (2001), Automobile exhaust catalysts, Applied Catalysis A: General,Vol. 221, pg. 443-457.

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

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

[22] Khanfekr A., Arzani K., Nemati A., Hosseini M.,(2009), Production of perovskite catalysts on ceramic monoliths with nanoparticles for dual fuel system automobiles, International Journal of Environmental Science and Technology, Vol. 6 (1), Pg.105-112.

[23] Kalavrouziotis K., Koukoulakis P.H., (2009),The environmental impact of the platinum group elements (Pt, Pd, Rh) emitted by the automobile catalyst converters, Water Air Soil Pollution, Vol. 196, Pg. 393-402.

[24] Shelef.M., Otto N., Otto N.C., Poisoning of Automotive Catalysts, Advances in Catalysis, Vol. 27 Pg.311- 365.

[25] Beck D.D., Sommers J.W., Dimaggio C.L., (1997), Axial characterization of oxygen storage capacity in closed coupled light of and underfloor catalytic converters and impact of sulfur, Applied Catalysis B: Environmental,Vol. 11, Pg.273-290, 1997.

[26] Koltsakis C., Stamateios A., (1997), Catalytic automotive exhaust after treatment, Progress in Energy Combustion Science, Vol. 23, Pg. 1-39.