Experimental Investigation for Emission Reduction from SI Engine using TiO_2 (Titanium Oxide) Catalytic Converter

Meetrajsinh Solanki[1], Viranchi Shastri[2], Haresh A Patel[3]
Department of Automobile Engineering Ganpat University – UVPCE
Kherva-Mehsana, India

Abstract- A catalytic converter is a device used to reduce the toxicity of emissions from internal combustion engines used in Automobile Industries. All the present day vehicles are equipped with catalytic converter. The main function of catalytic converter is to convert CO (Carbon Monoxide), HC (Hydrocarbon) and NO_x (Nitrogen Oxides) to O_2 (Oxygen), CO_2 (Carbon Dioxide), H_2O (Water) and N_2 (Nitrogen). In the present work, design specifications of catalytic converter for petrol engine have been presented. According to this design catalytic converter is developed and installed on single cylinder Briggs & Stratton 305 cc petrol engine. Chemicals used in this model are TiO_2 (Titanium Oxide), Cu $(NO_3)_2$ (Copper Nitrate), ZiO_2 (Zirconium Dioxide) and C (Charcoal) rather than Palladium, Platinum and Rhodium. Finally, the model with limited backpressure was fabricated and tests were carried out on B&S Engine using Indus 5 Gas Analyser (Model No. PEA 250N). The performance of the catalytic converter was discussed.

Keywords - Titanium Oxide, Perforated Ceramic Discs, Catalytic Converter, Emission Reduction

I. Introduction

The catalytic converter has been in use for the past 30 years as an efficient and economical solution for the reduction of pollutants emitted by the internal combustion engine, the later being the power train for almost all vehicles in use today. The widespread use of the catalytic converter was the response of the automotive industry to the legislation of developed countries, which poses limits to the most important gaseous pollutants emitted by both gasoline and diesel engines. Since the concern about the environmental impact of the emissions of the vehicles fleet is steadily growing— especially in urban areas, where air pollution has become a major issue—emission legislation becomes gradually stricter. Accordingly, this has led to continuous efforts of the automotive industry to improve the efficiency of the catalytic converter. Today's emission standards have been lowered so much that the catalytic converter technology has been pushed to its limits and it became apparent that, in order to build vehicles that comply with the legislation, automotive engineers should tune the whole system of engine, piping, and catalytic converter. Thus there emerged the need to view the catalytic converter as a component of an integrated exhaust after treatment system that should be designed very accurately. In this context, the role of modelling of the components of exhaust after treatment systems is becoming increasingly important, especially as regards the catalytic converter, which is the most crucial device of such systems. Since the introduction of catalytic converters in production vehicles, catalytic converter models have been appearing in the literature in parallel with the development of new catalytic converter technologies. Nevertheless, the accuracy, reliability, and application range of catalytic converter models is still questioned. The number of modelling applications in the automotive industry remains limited, especially when contrasted to the plethora of models that appear in the literature. It seems that a complicated landscape of approaches and methodologies has been created, causing an uncertainty as regards their validity and applicability. Most probably, this adversely affects their application in everyday practice, although modern modelling methodologies have been greatly improved and, in many cases, they have been successfully incorporated in the process of exhaust after treatment systems design.

The effect of parameters such as diameter of catalytic converter, length of catalytic converter, substrate used and cone angle have to be taken into consideration while designing the model [1],[2]. The new catalytic converter can be developed based on the catalyst used in the converter. The currently used catalysts are Platinum, Rhodium and Palladium these are very high cost catalyst. Hence, the cost of the catalytic converters is also very high [3]-[5]. The pressure drop in catalytic converters is associated with two major components: substrate and flow distribution devices [6]-[8]. The optimum design of the diffuser is the one having moderate diffuser half angle for most part of its length and then gradual but stepper diffusion in the later part along with a smooth wall curvature [9],[10]. The increasing price of Palladium (Pd), Platinum (Pt), and other noble metals even further stimulates search for inexpensive and easily available catalysts. This provides a remarkable opportunity to develop new nickel catalysts [11]-[13]. A hexagonal-shaped cell gives a better mechanical performance (lower pressure drop) than a square-shaped cell. On the other hand, a square-shaped cell performs better chemically (higher specific surface area) than a hexagonal-shaped cell. Overall, a hexagonal-shaped cell is more desirable than a square-shaped on because the former causes a 43% lower pressure drop [14]-[16]. It is experimentally found that the conversion efficiencies of TiO_2/Co based catalytic converter are 93%, 89% and 82% for NO_x, CO and HC emissions respectively [17],[18]. In the harsh conditions experienced 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 [19]-[21]. In order to oxidize HC and CO gases using thermal system, a residence time of greater than 50 ms and temperature excess of 600ºC to 700ºC are required (Heywood 1989). Temperature high enough for some homogeneous thermal oxidation can be obtained by spark retarded (with some loss in efficiency) and insulation of the exhaust ports and manifold. The residence time can be increased by increasing the exhaust manifold volume to form a thermal reactor [22],[23]. There is incomplete combustion of the fuel and this leads to emissions of the partial oxidation product, carbon monoxide (CO), oxides of nitrogen (NOx) and a wide range of volatile organic compounds (VOC), including hydrocarbons (HC), aromatics and oxygenated species[24],[25].

II. EXPERIMENTAL PROCEDURE

A. Catalyst Material

The conventional three-way catalytic converters use precious noble metals such as platinum, palladium and rhodium as catalyst but here titanium based catalytic converter is being made using non precious metals.

There are three catalyst material purchased to prepare titanium based catalytic converter,

1. Titanium Dioxide.
2. Copper Nitrate
3. Zirconium Dioxide

- *Titanium Dioxide*

  Titanium dioxide also known as titanium (IV) oxide or Tatiana, is the naturally occurring oxide of titanium, chemical formula TiO_2. It has a wide range of applications, from paint to sunscreen to food colouring. When used as food colouring, it has E number.

  Titanium dioxide occurs in nature as well-known minerals rutile, anatase and brookite, and additionally as two high pressure forms a monoclinic baddeleyite. It has mainly source from ilmenite ore. Rutile is the next most abundant and contains around 98% titanium dioxide in the ore. The metabaseanatase upon heating reaches temperature in the range 600ºC to 800ºC.

Fig:1 Titanium Dioxide [3]

- *Copper Nitrate*

Copper nitrate is an inorganic compound that forms a blue crystalline solid. Anhydrous copper nitrate forms deep blue green crystals and sublimes in a vacuum at 150-200ºC. Copper nitrate also occurs as five different hydrates, the most common ones being the trihydrate and hex hydrate, these materials are more commonly encountered in commerce than in the laboratory.

Fig:2 Copper Nitrate [3]

Hydrated copper nitrate can be prepared by hydration of the anhydrous material or by treating copper metal with an aqueous solution of silver nitrate or concentrated nitric acid.

- *Zirconium Dioxide*

Zirconium dioxide sometimes known as zirconia, is a white crystalline oxide of zirconium. It is most naturally occurring from, with a monoclinic crystalline structure, is the mineral baddeleyite. Zirconia is produced by calcining zirconium compounds, exploiting its high thermal stability. Zirconia is chemically unreactive. It is III. Experiment and Result slowly attacked by concentrated hydrofluoric acid and sulphuric acid. When heated with carbon, it converts to zirconium carbide.

Fig:3 Zirconium Dioxide [3]

When heated with carbon in the presence of chlorine, it converts to zirconium tetrachloride. This conversion is the basis for the purification of zirconium metals and is analogous to the roll process.

Table: 1. Properties of Catalyst Material

Molecular Formula	TiO_2	Cu $(No_3)_2$	ZiO_2
Density	4.23 g/cm^3	3.05 g/cm^3	5.68 g/cm^3
Melting Point	1843ºC	2715ºC	256ºC

Table: 2. Various Causes of failure

No.	Failure mode	Technical Description	Effect
1	Converter Meltdown	Excess heat generation due to long reaction time to clean up excess HC or CO	Small particles Come apart and clog the flow of exhaust through converter
2	Carbon Deposit	Contamination like carbon, oil, coolant and other stuff	Reduces surface area thus efficiency
3	Catalyst Fracture	Deposition of clogged particles	Loss of power at higher engine speed, hard to start, poor acceleration
4	Poisoning	Chemical Reaction	Harmful gases and acids
5	Reduced Engine Performance	Back pressure	Engine speed fuel economy

To improve all the factors described in the table 2, we decided to go with ceramic based perforated discs as catalyst for better surface area contact with no back pressure.

B. Design Calculation

SHAPE OF CATALYTIC CONVERTER

The cylindrical shape was considered due to ease of fabrication, minimum assembly time, rigidity and easier maintenance.

VOLUME OF CATALYTIC CONVERTER

Assuming space velocity (for single cylinder engine) = 30000 hr^{-1}

Table: 2. Specification of engine

Particular	Specification
Displaced volume	305 cc
Stroke length	61.978 mm
Bore diameter	79.248 mm
Engine speed	2800 rpm

Converter volume is calculated as under

- Volume flow rate = $\frac{\pi}{4} * d^2 * \ell * \frac{N}{2} * 60$ (1)

  $= \frac{3.14}{4} * (79.248)^2 * (61.978) * \frac{2800}{2} * 60$

  = 25677190100 mm^3 / hr.

  = 25.699 m^3 / hr.

- Converter volume = $\frac{Volume\ Flow\ Rate}{Space\ Velocity}$ (2)

  $= \frac{25677190100}{30000}$

  = 855906.3367 mm^3

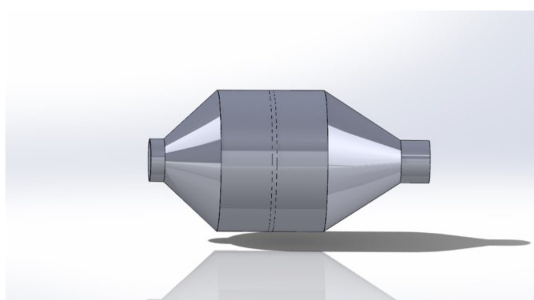

Fig: 4. 3-D Concept model of catalytic converter

- Shell dimensions

  The Shell is the central cylindrical part between the two inlet and outlet cones. This part contains circular discs with coated pellets.

Volume = 855906.3367 mm^3

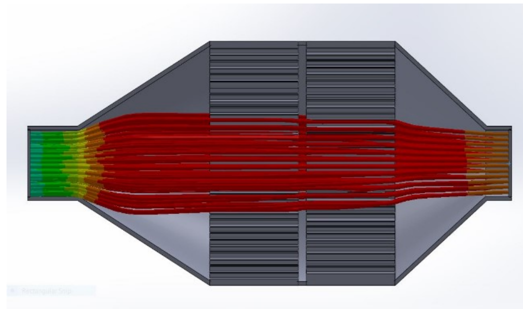

Fig:5 Flow analysis on catalytic converter

Converter Volume = $\pi * r^2 * \ell$ (3)

Then,

$\pi * (48)^2 * \ell = 855906.3367$

$\ell = 103.24$ mm

- Angle of divergence = 45º
  Angle of convergence = 30º

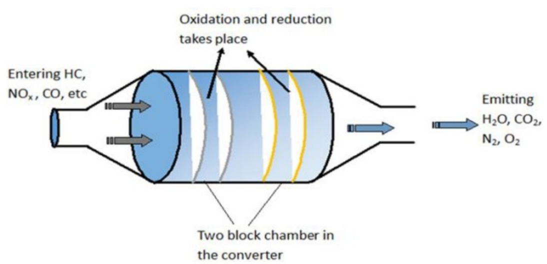

Fig:6 Converting system in catalytic converter[26]

C. Fabrication of Catalytic Converter

- Inlet cone was fabricated for converter housing.
  Exhaust gases from the engine are admitted through inlet cone
- Outlet cone was fabricated.
  Eco-friendly exhaust gases come out at this end.
- Cylindrical spacer and two circular housing with provision for putting pellets were fabricated.
- Pellets of different catalytic materials were developed.
- The components were assembled and fitted to engine exhaust manifold**.**

Perforated ceramic discs are used to create more surface area.

- Ceramic has very high melting point.
- Great hardness and strength to overcome fractures
- Chemical inertness (they are non-reactive with other chemicals).
- Considerable durability (they are long-lasting and hard-wearing).

Fig:7 Perforated ceramic discs

D. Coating process

Catalytic converters are used in automobile and industries for pollution abatement. They usually consist of cordierite ceramic extruded to form a structure of honeycomb-like cells that extend as channels along the catalytic converter length. A paint-like liquid containing the precious metal catalyst is coated on the channel walls. During operation, exhaust gases are conveyed with low pressure drop through the catalytic converter. The pollutant gases are removed by catalytic activity in the catalyst coating.

The slurry of titanium oxide (TiO_2), copper nitrate ($Cu(NO_3)_2$, Zirconium dioxide (ZrO_2) and charcoal is made and ceramic discs are dipped into slurry for 24 hours for impregnation and then after discs are kept to drying for next 24 hours and the results are shown in fig:7

Fig:8 Material preparation for coating

Fig:9 Ceramic disc installation in shell

Fig:10 Aligning shell substrate

II. RESULTS AND DISCUSSIONS

The experiment was conducted with the catalytic converter in single cylinder four stroke B&S petrol engine. The catalytic converter was fitted on the engine exhaust. Then the performance study was conducted and plotted against the proportion of HC, CO and NO_x reading taken at equal time interval and tested for two speeds – Idle and Full throttle conditions with and without catalytic converter to determine the reduction in pollutants.

Table: 3 Results with and without catalytic converter

TEST CONDITIONS	IDLE (Low Speed)			FULL THROTTLE (High Speed)		
CATALYTIC CONVERTER	WITH	W/O	% REDUCTION	WITH	W/O	% REDUCTION
HYDROCARBON, HC (PPM)	415	1224	66.09%	11	101	92.07%
CARBON MONOXIDE, CO (%)	2.5	4.4	43.18%	2.2	3.9	43.58%
NITROGEN OXIDE, NO_x (PPM)	54	120	55%	36	219	83.56%

IV.CONCLUSION

Based upon the work presented in the paper, the following conclusions can be drawn.

• The special shaped catalytic beads allow the exhaust gas to flow freely without making any obstruction or blocking.

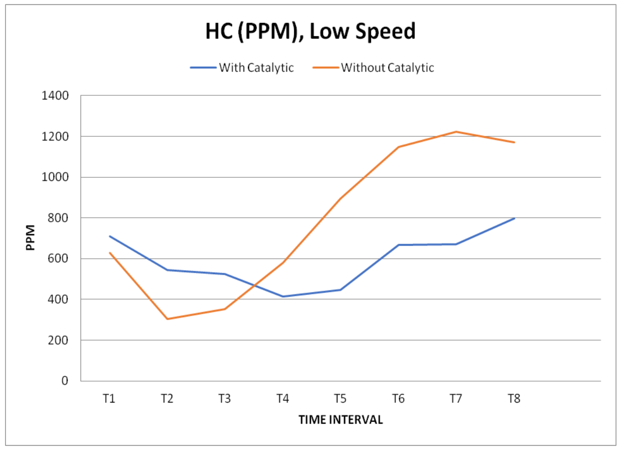

Fig: 11 Hydrocarbon at low engine speed

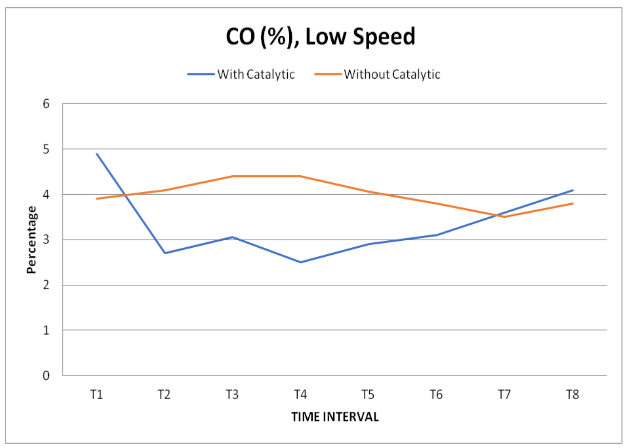

Fig: 12 Carbon monoxide at low engine speed

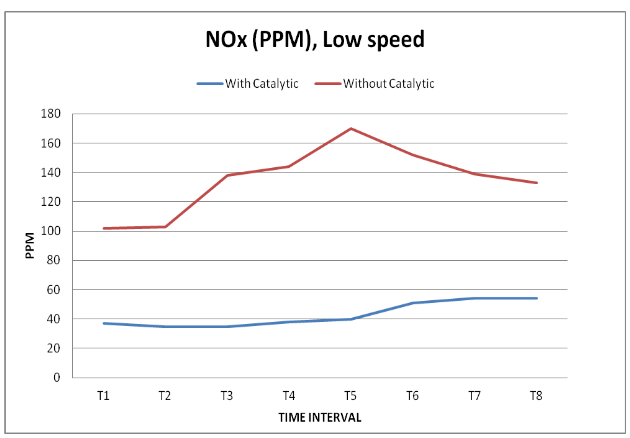

Fig: 13 Oxides of nitrogen at low engine speed

• Availability of chemicals like Titanium oxide, Copper nitrate, Zirconium dioxide and charcoal compared to noble materials makes the advanced catalytic convertor more useful.

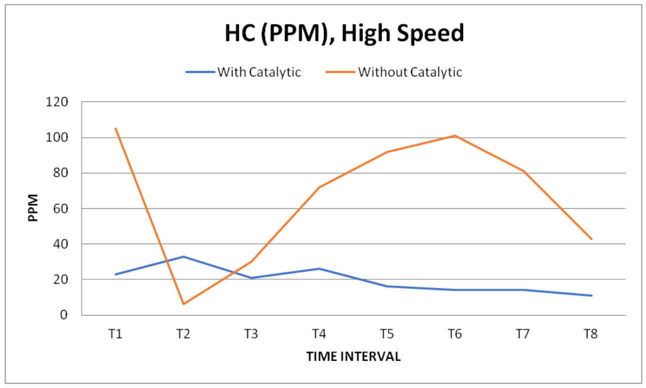

***Fig: 14** Hydrocarbon at high engine speed*

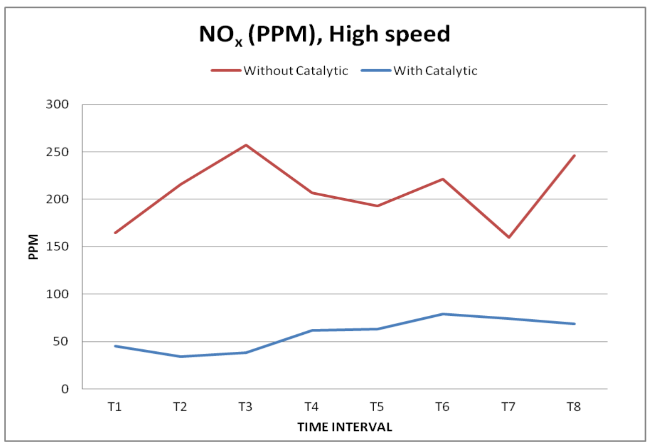

Fig: 15 Oxides of nitrogen at high engine speed

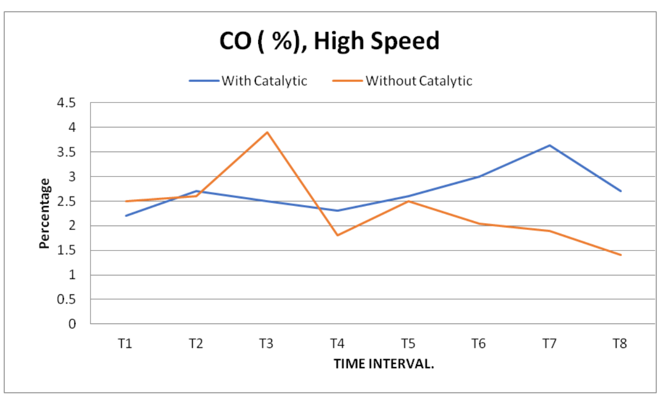

Fig:16 Carbon monoxide at high engine speed

• Ceramic coating results into reduction of catalyst fracture and convertor meltdown problems.

• The results of controlling emissions have revealed which states the performance of new catalytic converter and effectiveness of converting harmful compounds from the exhaust of engine. On comparing with and without catalytic converter testing resulted in reduction in HC, CO and NO_x as shown in the fig. 11-16 at different engine speeds.

Acknowledgement

The author would like to thanks Head of Department, Mechanical and Automobile Engineering Department, Ganpat University – UVPCE, for providing all the required support in carrying out this research project. Also extend gratitude to Maruti Suzuki Japan India Institute of Manufacturing for permitting to use its resources.

REFERENCES

[1] Rajat.S.Panday, Siddarth Mohanty, Tanmay Kumar, Siddarth Srivastava " Two way catalytic converter for 305 cc Go-kart" 2017 International Journal of Innovative Research in Science Engineering & Technology, vol-6 Issue-4

[2] Douglas Ball, Michael G. Zammit and George C. Mitchell, Effects of Substrate Diameter and Cell Density FTP Performance, SAE Technical Papers 2007-01-1265.

[3] R. Yuvaraja, K. Nanthakumar, G. Dhasah Morthi "Development and Performance Analysis of New Catalytic converter" 2015 International Journal on Application in Mechanical & Production Engineering

[4] Steffen Wagloehner, Sven Kureti, "Study on the mechanism of the oxidation of soot on Fe2O3 catalyst", Applied Catalysis B: Environmental, vol. 125, 2012, pp. 158– 165.

[5] Ronald M. Heck, Robert J. Farrauto, "Automobile exhaust catalysts", Applied Catalysis General, vol. 221, 2001, pp. 443–457.

[6] P. Karuppusamy and R. Senthil, "Design, analysis of flow characteristics of catalytic converter and effects of backpressure on engine performance," Int. J. of Research in Engineering & Advanced Technology, ISSN: 2330-8791, Vol 1, Issue 1, March 2013

[7] Manuel Presti, Lorenzo Pace, Jan Hodgson, A Computational and Experimental Analysis for Optimization of Cell Shape in High Performance Catalytic Converters, Society of Automotive Engineers, Inc. 2002 – 01 – 0355.

[8] Thundil Karuppa Raj R. and Ramsai R., Numerical study of fluid flow and effect of inlet pipe angle In catalytic converter using CFD, Research Journal of Recent Sciences ISSN 2277-2502 Vol. 1(7), 39-44, July (2012).

[9] G S Kulkarni, S N Singh & Ratan Mohan, Optimum diffuser geometry for the automotive catalytic converter, Indian Institute of Technology, New Delhi.

[10] Daniel W Wendland. John E Krucher and Eric Anderson. Reducing catalytic converter pressure loss, Automotive Engineering, SAE Publication, (June 1996), 69-74.

[11] Valentine P. Ananikov, "Nickel: The „Spirited Horse of Transition Metal Catalysis", ACS Catal., 2015, 5, pp. 1964-1971.

[12] Ananikov, V. P.; Beletskaya, I. P. Dalton Trans. 2011, 40, 4011−4023.

[13] Eremin, D. B.; Ananikov, V. P. Organometallics 2014, 33, 6352−6357.

[14] S. H. Amirnordin, W. Salim " Pressure drop Analysis of Square and Hexagonal Cells and its effects on the Performance of Catalytic Converters" International Journal of Environmental science and Development, June 2011

[15] G.M Pannone and J.D Mueller, "A comparison of conversion efficiency and flow restriction performance of ceramic and metallic catalyst substrate," SAE International, 2001-01-0926, 2001.

[16] M. Lashmikantha and M. Keck,"Optimization of exhaust systems," SAE International, 2002-01-0059, 2002.

[17] M A Kalam, H H Masjuki, M Redzuan, Development and test of a new catalytic converter for natural gas fuelled engine, Sadhana Vol. 34, Part 3, June 2009, pp. 467–48

[18] Avila P, Montes M, Miro E E 2005 Monolithic reactors for environmental applications. A review on preparation technologies. Chemical Engineering Journal 109: 11–36

[19] J. Kaspar, P. Fornasiero, and N. Hickey, ″Automotive catalytic converters: current status and some perspectives″, Catalysis Today, vol. 7, pp. 419 - 449, 2003.

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

[21] A. Bera, and M. S. Hegde, "Recent advances in auto exhaust catalysis", Journal of the Indian Institute of Science, vol. 90:2, pp.299-325, 2010

[22] Heywood J B 1989 Internal combustion engine fundamentals, (New York: McGraw-Hill)

[23] Eric V S, Gary S S, Rafene A M, Craig M, Heiko M, Martijn D L, Cyril T C 1996 tpr study on the preparation of impregnated CO/siO2 catalysts. J. Catalysis 162: 220–229

[24] Chirag Amin, Pravin P. Rathod; Catalytic Converter Based on Non-Noble Material; International Journal of Advanced Engineering Research and Studies (IJAERS); E-ISSN: 2249-8974, Vol. I, Issue II, January-March (2012), p:118-120

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

[26] P. Bera, and M. S. Hegde, "Recent advances in auto exhaust catalysis", Journal of the Indian Institute of Science, vol. 90:2, pp.299-325, 2010.