ISSN (Print 0974-2115) (Online 2349-8552)
www.jchps.com Journal of Chemical and Pharmaceutical Sciences

Design and Development of Non Novel Based Catalytic Converter for DI Diesel Engine

Dillip Kumar sahoo*, G. Mathiselvan
Dept. of Automobile Engg, Sathyabama University, Chennai
***Corresponding author: E-Mail: dillipkumarsahoo@gmail.com**

ABSTRACT

The intent of the paper is to design and improve a low cost three way non noble based catalytic convertor using titanium oxide (TiO_2) and Co oxide (CO_3O_4) as oxidization and reduction catalysts in preference to Pt (Pt), palladium (Pd) and rhodium (Rh) that were used as catalyst materials since 1980 to reduce exhaust emission (NO, HC, CO) from exhaust system of automobiles.

A new improvement in design has been made inside the catalytic converter by coating wire mesh substrate with TiO_2 and CO_3O_4 as substitute of honeycomb structure coated with platinum Palladium and Rhodium. Symmetrical modeling of catalytic converter was prepared using creo and solidworks. Flow transfer report of mass and gas was done using Ansys fluid flow software. TiO_2 and CO_3O_4 catalytic materials are reasonably priced in comparison to Nobel metals. In addition to that the Nobel metals are now acknowledged as human health hazard due to swift emission. It is experimentally found that TiO_2 and CO_3O_4 based catalytic converter can reduce 27%, 37% and 32% higher NO, HC and CO emissions in comparison with conventional catalytic converter. Detailed design analysis, fabrication methodology of the project and result on CI engine has been presented in this paper.

KEY WORDS: Catalytic converter, TiO_2 and CO_3O_4 catalyst, Emissions.

1. INTRODUCTION

In Internal combustion engines, the time available for combustion is restricted by the engine's cycle to simply a couple of milliseconds. There is incomplete combustion of the fuel and this results in emissions of the partial oxidation product, carbon monoxide (CO), oxides of nitrogen (NOx) and a wide vary of volatile organic compounds (VOC), including hydrocarbons (HC), aromatics and oxygenated species. Carbon monoxide is a product of a partial combustion of hydrocarbons in fuel. It is always present when there's a scarcity of oxygen throughout combustion and therefore directly dependent on the applied engine air/fuel ratio. NOx is formed during combustion in the engine when oxygen reacts with nitrogen due to a high combustion temperature. NOx emissions either increases or decreases, as it strongly related to combustion temperature characteristics that depend upon air–fuel ratio and fuel injection system. However, the gaseous pollutants from engine exhaust will be reduced either by thermal or chemical action system. In order to oxidize HC and CO gases using thermal system, a time of greater than 50 ms and temperature excess of 600^0C to 700^0C are required (Heywood, 1989). Temperature high enough for some homogeneous thermal oxidization are often obtained by spark retarded (with some loss in efficiency) and insulation of the exhaust ports and manifold. The residence time are often increased by increasing the exhaust manifold volume to create a reactor (Pundir, 2017). However, this approach has limited application. Hence, the catalytic convertors are the simplest way to scale back exhaust pollutants.

A catalytic converter is a device used in automobiles used for the reduction of the toxicity and content of harmful emissions coming from the exhaust system of internal combustion engines. Inside of catalytic converter consists of ceramic honey comb structure coated with precious and expensive metals such as platinum (Pt), palladium (Pd), rhodium (Rh) as catalyst materials for reducing and oxidizing of harmful products such as HC, CO, NOx, coming from exhaust system. The catalytic converter is placed between engine manifold and exhaust tailpipe.

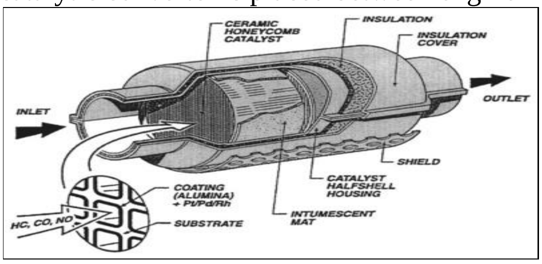

Figure.1. Catalytic converter

It can be aforesaid that a catalytic converter consists of steel covering or steel box, monolithic substrate (used to make cannular walls), wash coat (as binder) usually alumina on that catalyst materials like platinum, Rh, Pd. Apart from catalyst materials, CeO_2, or CeO_2- ZrO_2 mixed oxides are additionally added within the wash coat of 3 method catalytic (TWC) device for improved oxygen storage capability and thermal stability of alumina (Osawa, 1998; Kaspar, 1999). The thermal aging of the catalytic converter might have an undesirable impact on each catalyst substrate and noble metal load in numerous ways. For operation temperatures of the catalytic converter above 600^0C, Rh_2O_3 reacts with alumina to form inactive $Rh_2Al_2O_4$ (Forzatti & Lietti, 1999), while above 700^0C, Pt sintering occurs. For temperatures higher than 900^0C, sintering of γ -Al_2O_3 and alloying of the noble metals may occur. At even higher temperatures, severe sintering of γ -Al_2O_3 undergoes as a result of its crystalline state, transformation into another as δ-Al_2O_3 or α-Al_2O_3, with a decrease in the alumina surface area. The conventional catalyst materials are primarily noble metals or platinum group metals like platinum (Pt), palladium (Pd), rhodium (Rh), ruthenium (Ru). All these materials have the common properties like inert as biological reactions or less chemical reactions; and to be immobile. However, the recent studies indicate that the application of those materials are extensively increased in vehicle exhaust catalyst, industry, jewelers, anticancer drug, in dentistry as alloy that cause their anthropogenic emission and unfold in the atmosphere. In this investigation, a new sort of catalytic converter based on CO_3O_4/TiO_2 materials has been developed with wire metal substrate to oxidize/reduction emissions from direct injection CI engine. The advantages of this convertor are declared as affordable, domestically available and higher substrate area which is economical to oxidize/reduction emission as compared to conventional catalytic converter.

Modeling and Analysis of Catalytic Converter:

Modeling of catalytic converter: Geometric modeling of catalytic converter was done using CREO 2.0 and solid works.

The catalytic converter has been designed with dimension of length of shell is 250 mm, outer and inner diameter of shell is 124 mm and 120 mm respectively. The inlet and exhaust pipe diameter has taken as 40 mm, Inlet and outlet core diameter has taken as 120 and 40 mm respectively.

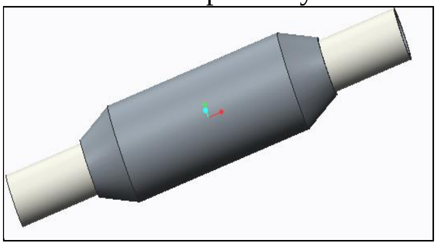

Figure.2. Model of the catalytic converter

A cut section was made along the x axis of the model for better view. This cut section make the model to cut into 2 pieces showing clearly inside parts how they have installed in catalytic converter. Inside wire mesh pieces are installed on a straight steel bar covered with an insulator sheet and then the outer shell. The red arrow in the fig.3, indicates the direction of other half of the model.

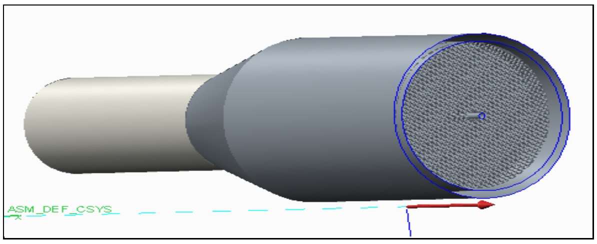

Figure.3. X axis cut section of model catalytic converter

A cut section has made along y axis for better view. This cut section makes the model to cut into two pieces along y axis. Figure.4, shows how the wire mesh pieces are installed inside the converter. The wire mesh pieces are arranged on a straight bar and installed inside. Wire mesh are installed separately for oxidation and reduction process.

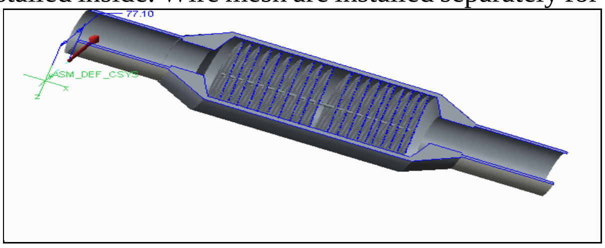

Figure.4. Y axis cut section of model catalytic converter

Analysis of catalytic converter: The nature of exhaust gas flow could be a vital consider determining the performance of the catalytic convertor. Of particular importance is the pressure gradient and velocity distribution through the substrate. Hence CFD analysis is used to vogue economical catalytic converters. By modeling the exhaust gas flow, the pressure drop and the regularity of flow through the substrate is determined. ANSYS FLUENT is used to model the flow of nitrogen through convertor geometry, so that flow fluid structure is analysed.

In this catalytic convertor Air flows in though inlet with a uniform speed of maximum 22.6 m/s and minimum 0 m/s, passes through non noble based chemical process convertor with titanium oxide and cobalt oxide coating on wire mesh substrate, and then exits through the outlet. Substrate is impermeable in Y and Z directions, which is modeled by specifying loss coefficients 3 order higher than in X direction.

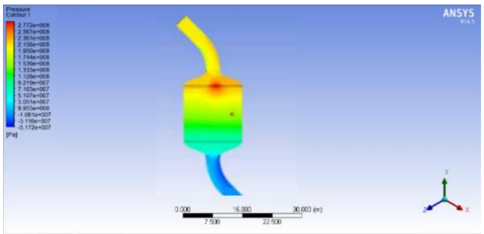

Figure.5. Pressure Drop through catalytic converter

As the air flows through the non-noble based catalytic converter, pressure is zero at the entrance of inlet pipe, the pressure will increase gradually with increase of distance through converter. Firstly pressure is zero at the entrance of inlet pipe, the pressure will increase to 72 pa at the exit of the inlet pipe. The pressure will remain constant up to the entrance of inlet cone. When the air passes through the inlet cone, the pressure will increase to 115pa and this pressure drop at the exit of inlet cone. When the air flows through the shell, as the shell contains wire mesh coated with titanium oxide and cobalt oxide. So, the pressure will increase from 118 pa to 427 pa .The pressure drop at the outlet of the shell is 427 pa. Then, the air enters the outlet cone and exhaust pipe. When the air flows through the outlet cone the pressure will increase from 427 pa to 433 pa. The pressure at the outlet of exhaust pipe is 454 pa.

Catalyst and Substrate Preparation:

Catalyst selection: In this study, several stock solutions with completely different liquid molar ratios and weight ratios were used. Titanium dioxide and cobalt oxide were used as a metal oxide catalyst. The pure CO is used because the agent and titanium dioxide is that the oxidizer. Its inertness to sulphate formation and surface properties makes it most popular carrier in selective catalytic reduction of NOx from the stationary pollution sources.

Substrate preparation for oxidation purpose: As per ratios 275grams of TiO_2 and 38grams of ZrO_2 were added to 900ml distilled water and then stirred for 10 minutes at a particular rpm. The main purpose of stirring is for effective mixture formation.

Coating of wire mesh pieces with oxidising agent (TiO_2): Stainless Steel wire mesh substrate of circular pieces are dropped in slurry and taken out and are allowed to dry at room temperature. After drying, heat the circular stainless steel wire meshes in oven at 600^0C for 4hours and assemble the wire mesh to the converter.

Substrate preparation for reduction purpose: As per requirement ratios 240grams of CO_3O_4, 36grams of ZrO_2 are added to 900ml of distilled water. The main purpose of stirring is for effective mixture formation.

Coating of wire mesh pieces with reducing agent CO_3O_4: Stainless Steel wire mesh substrate of circular pieces are dropped in slurry and taken out and are allowed to dry at room temperature. After drying, heat the circular stainless steel wire meshes in oven at 600^0C for 4hours and assemble the wire mesh to the converter.

Figure.6. (a) Wire mesh substrate are cut in circular shape (b) Arranged calcined wire mesh substrate

Catalytic Converter Fabrication:

Catalytic converter (catco) chamber: The fabrication of catalytic device consists of few components, namely the converter chamber, substrate and insulator. The catalytic device casing and chamber stay as same as originally installed into the vehicle system. The same outer dimensions were purposely fixed so as to avoid design of the present exhaust, which then needed more thermal optimization and design validation studies.

Figure.7. Collided view of catalytic converter

Substrate: After the heat treatment of wire mesh pieces. The coated wire mesh pieces are installed on a straight stainless bar of 0.3mm. The TiO_2 coated wire mesh are installed on left side. These wire mesh are for oxidation of HC to H_2O and CO_2. The CO_3O_4 coated wire mesh are arranged on right side of the bar. These wire mesh pieces are for reduction of NOx and CO to nitrogen, oxygen, carbon dioxide. A gap of 2cm is left between oxidation and reduction wire mesh pieces for the purpose of oxygen availability for oxidation process.

An insulator sheet made of wool of thickness 2mm is inserted inside the converter to reduce the vibrations of the engine. The coated wire mesh pieces which were installed on the straight bar of length 24cm and diameter 0.3mm was inserted inside the catalytic converter. The TiO_2 and CO_3O_4 coated wire mesh are arranged correctly so that CO_3O_4 comes to the inlet and TiO_2 coated wire. When the exhaust gas flows through the non-noble based catalytic converter. CO_3O_4 coated wire mesh pieces will do reduction and the TiO_2 coated wire mesh will do oxidation.

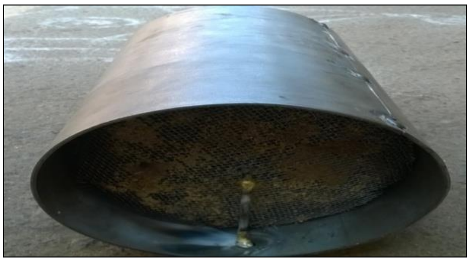

Figure.8. Coated wire mesh installed in outer shell of catalytic converter

Welding of outer shell: A mild steel of dimensions 390 mm x 250 mm has taken is rolled into circular shape of length 250mm and diameter of 12mm inside with help of roller machine. Then the end parts are welded with point welding.

TiO_2 and CO_3O_4 coated wire mesh pieces are arranged on a stainless steel bar. This bar is inserted inside the outer shell of converter. Then the bar is welded on both sides with gas welding. With the gas welding. The stainless steel bar of 6mm is welded to wire mesh arranged bar on one side and welded to outer shell on the other side.

After arc welding, cones of diameter 12cm on one side and 4cm on the other side are made with ms steel of thickness 2mm. The inlet and the exhaust cones are welded to the outer shell on both sides with Tig welding. The welding should be made without leaving any gaps to avoid gas leaks.

Catalytic Converter Test on A DI Diesel Engine: Both of the catalytic converters such as conventional catalytic converter based on Pt/Rh and new catalytic converter based on CO_3O_4/TiO_2 catalyst were tested at Engine and Fuel Testing Laboratory, Department of Mechanical Engineering, Sathyabama University. The test engine was a multi-cylinder compressed direct injection gas engine. DI diesel engine with a displacement of 661cc.compression ratio is 12:1 to 18:1, developing a power of 7kw at 3000 rpm.

Exhaust gas analyzer was used to measure the exhaust pollutants concentration. The engine was tested at wide open throttle (WOT) from power range from 0 KW to 7KW. The engine was operated at the maximum best torque (MBT) improvement which was achieved at the lambda value of 0.81.

The engine was tested without catalytic convertor (without catco), with conventional catalytic converter or original engine manufacture catalytic converter (OEM catco) and new CO_3O_4/TiO_2 primarily based catalytic converter (which may be expressed as wire mesh catco).

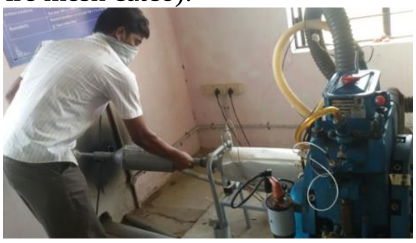

Figure.9. Installation of non-noble based catalytic converter on DI Diesel engine

3. RESULTS AND DISCUSSION

The emissions reading without and with catalytic converter were noted and plotted in various graphs. Figure.10, shows NOx emission versus engine load from 0 to 6.5 KW with and without catalytic converters. The test was conducted at wide open throttle (WOT). It is found that wire mesh converter produces lower level of NOx emission with an average of 74 ppm everywhere the engine load range followed by OEM converter (average 310 ppm).

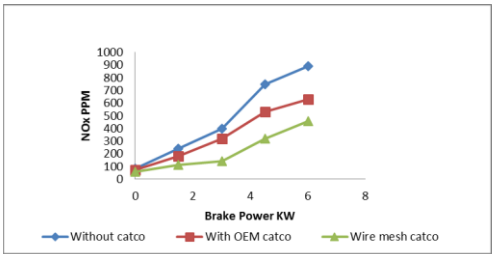

Figure.10. NOx Emission versus Engine load(with and without catalytic converter) with WOT

It can be calculated that the conversion potency of wire mesh and OEM catalytic converter(s) are 89 and 62 respectively. The wire mesh converter reduces 27% higher Nox emission than OEM catalytic converter. This is mainly as a result of the impact of metal oxide(s) such as TiO_2 with the higher wire mesh substrate area.

Figure.11, shows CO emission versus engine load from 0 KW to 6.5 KW with and without catalytic converters. The test was conducted at wide open throttle. It is found that wire mesh converter produces lower level of CO emission as an average of 0.34% everywhere the engine speed range followed by OEM catalytic converter (average 1.1%). It can be calculated that the conversion potency of wire mesh and OEM catalytic converter(s) are 83 and 51 respectively. The wire mesh converter reduces 32% higher CO emission than OEM catalytic converter. It can be explained that the higher specific area of the wire mesh substrate in comparison with the monolith substrate is useful at higher operational temperature.

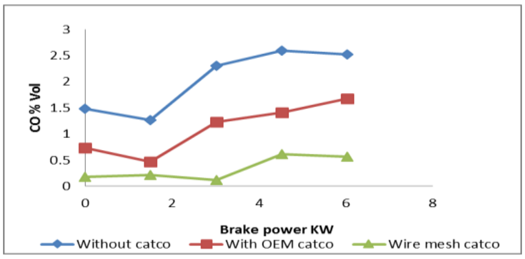

Figure.11. CO Emission versus Engine load(with and without catalytic converter) with WOT

Figure.12, shows HC emission versus engine load from 0 KW to 6.3 KW with and without catalytic converters at wide open throttle condition. It is found that wire mesh converter produces lower level of HC emission as an average of 50 ppm everywhere the engine speed range followed by OEM catalytic converter (average 140 ppm).

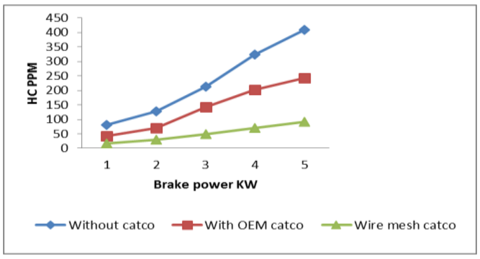

Figure.12. HC Emission versus Engine load(with and without catalytic converter) with WOT

It can be calculated that the conversion efficiency of wire mesh and OEM catalytic converter(s) are 81 and 44 yards respectively. The wire mesh converter reduces 37% higher HC emission than OEM chemical process converter. This is mainly because of the result of metal oxide(s) such as TiO_2/CO_3O_4 with the higher wire mesh substrate space.

4. CONCLUSION

- This study introduces a simple low cost; non noble (TiO_2/CO_3O_4) based catalytic device to reduce diesel motor exhaust emission and area of wire mesh substrate is about 28 times above ceramic substrate.
- The NOx conversion efficiency of OEM and wire mesh catalytic converters are 62 and 89 respectively. Wire mesh reduces 27% higher than OEM converter.
- The CO conversion efficiency of OEM and wire mesh catalytic converters are 51 and 83 respectively. Wire mesh reduces 32% higher than OEM converter.
- The HC conversion efficiency of OEM and wire mesh catalytic converters are 44 and 81 respectively. Wire mesh reduces 37% higher than OEM converter.
- Hence, TiO_2/CO_3O_4 oxide-based catalytic converter is effective for direct injection diesel motor.

REFERENCES

Abinesh J, Arunkumar J and Dinesh Kumar S, Engineer Trainee, Hepatica Technologies Private Limited, Bangalore, India, Minimization of engine emission by using non-noble metal based catalytic converter, International Journal of Development Research, 4 (11), 2014, 2463-2468.

Angelidis T N, Papadakis P G, Partial regeneration of an aged commercial automotive catalyst, J. Applied Catalysis B, Environmental 12, 1997, 193–206.

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

Bassem H, Ramadan and Philip C. Lundberg, Characterization of a Catalytic Converter Internal Flow, SAE paper, 2007.

Ettireddy PR, Rajender SV, Preparation, characterization and activity of Al_2O_3-supported V2O5 catalysts, J. Catalysis, 221, 2004, 93–101.

Forzatti P, Lietti L, Catalyst deactivation, Catalysis Today, 52, 1999, 165–181.

Heywood J B, Internal combustion engine fundamentals, 1st edition, McGraw-Hill publisher, New York, 1989.

Kalam M A, Masjuki H H, Development and test of a new catalytic converter for natural gas fuelled engine, International Journal of Engineering Sciences & Research Technology Design, 34 (3), 2009, 467–481.

Kielhorn J, Melber C, Keller D, Mangelsdorf I, Palladium—A review of exposure and effects to human health, Int. J. Hyg. Environ. Health, 205, 2002, 417–432.

Merget R, Rosner G, Evaluation of the health risk of platinum group metals emitted from automotive catalytic converters, The Science of Total Environment, 270, 2001, 165–173.

Osawa M, Role of cerium–zirconium mixed oxides as catalysts for car pollution, A short review, J. Alloys and Compound, 27 (5), 1998, 886–890.

Pundir P, Engine emissions pollutant Formation and Advances in Control Technology, Narosa Publishing house, New Delhi, 2nd edition, 2017, 1-10.

Ravindra K, Bence L, Grieken RV, Platinum group elements in the environment and their health risk, The Science of Total Environment, 318, 2004, 1–43.

Umit SO, Mahesh WK, Gurkan K, Characterization and temperature-programmed studies over Pd/TiO_2 catalysts for no reduction with methane, Catalysis Today, 40, 1998, 3–14.

Yuvaraja R, Nanthakumar K, Dhasahinamoorthi G, Development and Performance Analysis of New Catalytic Converter, International Journal on Applications in Mechanical and Production Engineering, 1 (6), 2015, 17-23.