ISSN XXXX XXXX © 2017 IJESC

Research Article Volume 7 Issue No.7

# Design, Analysis & Testing of Catalytic Converter for Emission Reduction & Backpressure Optimization

Utkarsh Suhas Wani[1], A.B. Korane[2], V.N. Kapatkar[3]
BE Student[1], Assistant Professor[2], HOD[3]
Department of Mechanical Engineering
Sinhgad College of Engineering, Pune, India

**Abstract:**
In this paper, the development of a catalytic converter for back pressure minimization and efficient emission reduction is presented. Different models of catalytic converter are studied based on different parameters such as cell shapes and sizes, CPSI configuration and inlet cone angle. Also, effect of different types of catalyst with respect to reduction in the emission of HC and CO is studied. The results are presented after performing Computational Fluid Dynamics (CFD) on the proposed catalytic converter. Three different types of catalyst coatings are experimented to choose the optimum one, which include Nickel coated monolith substrate, Copper coated wire mesh and $TiO_2$ coated wire mesh. Gas Analyzer is used to measure the emissions. The results show that corrugated cell shape provides large surface area when exposed to the emission gases. Also, it is seen that converter size has a major effect on the performance of the converter. Finally, Nickel coated monolith structure provides 50% HC reduction and 60% CO reduction with minimum pressure drop and maximum turbulence.

**Index terms:** catalytic converter, backpressure, optimization, CFD.

## I. INTRODUCTION

Automobiles throughout the world are the primary consumers of fossil fuels, which emit toxic gases when burnt; including HC, CO and NOx. Catalytic converters were developed to detoxify these gases into less harmful gases such as carbon dioxide and $H_2O$. OEM catalytic converters are built for commercial vehicles and use noble elements including, Platinum (Pt), Palladium (Pd) and Rhodium (Rh). In 2003 Joachim Braun[10] at the University of Heidelberg carried out research in catalytic converter. He studied the temperature distribution with the help of CFD analysis immediately after startup of an engine and after about 41seconds. Uniform temperature distribution was observed. He observed that time lag was required to activate the catalyst. Rolf Bruck [11] felt that solution for Euro 5 norms and beyond would be to use turbulent flow catalyst. Emitec has introduced two new channel structures that create turbulent like flow condition thus increasing catalytic efficiency. One of the aim of this study is to develop a catalytic converter with available elements other than noble elements, which cost much higher. The catalytic converter has been specifically designed for a Briggs and Stratton 305 CC engine used to power an All-Terrain vehicle (ATV). The main objective of this study was to observe pressure drop for different converter designs with respect to geometry and structure of the substrate.

## II. LITERATURE REVIEW

The use of catalytic surface to enhance chemical reaction is a well-established and common practice. Catalysts are extensively used for exhaust treatment of automotive engines [1, 2, 3]. However, its use in combustion devices for improving combustion rate is somewhat less common and limited to aircraft combustor applications [4, 5]. Karim and Kibrya [6] have done detailed experimental work to compare the catalytic activation of eight different metals and found out that platinum and copper showed better performance. Ramesh Babu et al. [7] have studied the effect of different catalytic coatings on the exhaust emissions of a four-stroke engine. The results indicated that copper as a catalyst was very effective with significant reduction in HC and CO emissions with lean combustion in a four-stroke SI engine. In the present study, non-noble metal catalysts such as copper, nickel and chromium have been used as catalyst and they are coated inside the combustion chamber walls. Detailed experimental study has been carried out to evaluate the catalyst performance and its influence on combustion and exhaust emission at various speeds

## III. MODELING OF CONVERTER

The objective of this study was to determine the effect of geometry of the inlet cone of the catalytic converter on the pressure drop and heat-mass flow distribution. Different cell shapes such as square, triangular, hexagonal &corrugated [8] and cell sizes of 100 and 200 Cells per square inch (CPSI)[1,2]. CFD analysis enabled to observe the pressure drop in each of these shapes and sizes. The catalytic converter chamber was designed while considering the engine specifications which are as follows:

| | |
|---|---|
| Engine type | Briggs & Stratton 10 HP |
| Swept Volume | 305cc |
| Engine Speed (N) | 2800 |
| Bore Diameter (d) | 0.08178 m |
| Stroke (L) | 0.05791 |

$$\text{Space Velocity} = \frac{Volume\ \ Flow\ \ Rate}{Catalyst\ \ Volume} \quad (1)$$

For Single Cylinder,
Space Velocity = 30,000 $hr^{-1}$
Volume Flow Rate = Swept Volume × No. of intake strokes
$= \frac{\pi}{4} \times d^2 \times L \times \frac{N}{2} \times 60$ (2)
$= \frac{\pi}{4}(0.08178)^2 \times 0.05791 \times \frac{2800}{2} \times 60$
$= 25.55\ m^3/hr.$
Catalyst Volume $= \frac{25.55}{30000}$
$= 0.000851\ m^3$

**Shell Dimensions:**
For $L = 2D$
Volume = Area × Length
$0.000851 = \frac{\pi}{4} \times D^2 \times 2D$
$D$ = 80mm
$L$ = 160mm

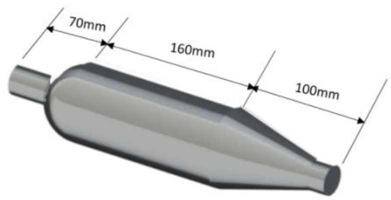
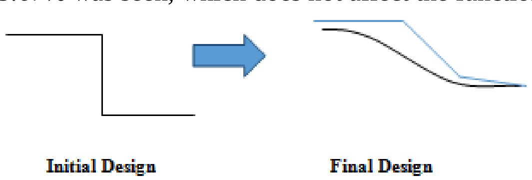



**Figure.1. Converter Geometry**

## IV. DESIGN FINALIZATION BASED ON NURBS CRITERIA NURBS-

Non-uniform rational basis splines are used to generate a curve using the given constrained tangents [5]. Using the same concept here, the 90° step was discretized and semi polygonal structure was developed. This structure was then converted to a smooth curve. This was done using iterative method. Volumetric error of 5.67% was seen, which does not affect the functionality.



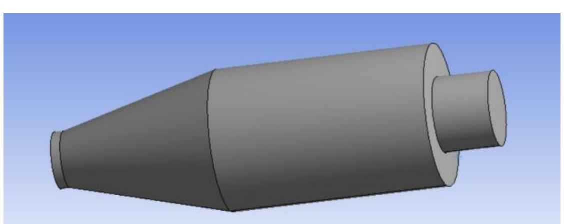



**Figure.2.(a)Chamber design with step outlet**

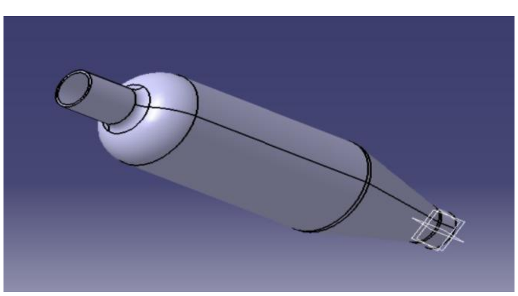
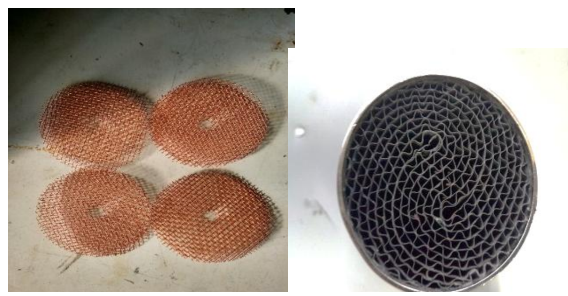


**Figure.3. (b) Chamber design with fillet**

## V. CATALYST SELECTION

A trial study was conducted on three types of substrates which consisted of Nickel coated monolith substrate, Copper coated wire mesh and $TiO_2$ coated wire mesh[6]. These substrates were assembled in the converter shell and the emissions were measured with the help of the Gas Analyzer equipment available with the department of Mechanical Engineering at SCoE. The criterion for the selection of converter was minimum pressure drop and chaotic gas flow distribution, combined with efficient reduction values. The monolith substrate was coated with a 10 microns' thick layer of Nickel [7]. Similarly, the wire mesh was coated with 15 microns thick layer of Copper. This is shown in Fig. 2(a). For applying the wash coat of the $TiO_2$ slurry on the wire mesh, dipping technic was used. This is shown in Fig. 2 (c). After applying the wash coat, all the meshes were assembled in a shaft (bolt) to function as a catalyst.



**(a)** **(b)**

**(c)**

**Figure.4. (a) Copper coated wire mesh, (b) Nickel coated monolith & (c) $TiO_2$ coated wire mesh substrates**

## VI. CHEMICAL KINETICS

Nickel has proved to be a younger sibling of Palladium in the field of transition metal catalysis. It has number of readily available oxidation states commonly invoked in catalysis. Ni (0)/Ni (II) catalytic cycles are wide spread but the easy accessibility of Ni (I) and Ni (III) oxidation states allows different modes of reactivity and radical mechanisms. Considering this, Ni (III) was chosen.

## VII. CFD ANALYSIS

CFD analysis is able to predict flow fields, even combined with heat transport, due to recently developed numerical algorithms. The careful choice of physical parameters like inlet and boundary conditions is a pre-condition for reliable simulation results[3]. CFD analysis was performed on various converter designs integrated with substrates of different CPSI. The considerations for this analysis were the inlet fluid velocity, inlet temperature and outlet relative pressure. The procedure followed includes setting the boundary conditions i.e. inlet and outlet diameters, applying the inlet velocity and temperature, providing time step and initializing the run.

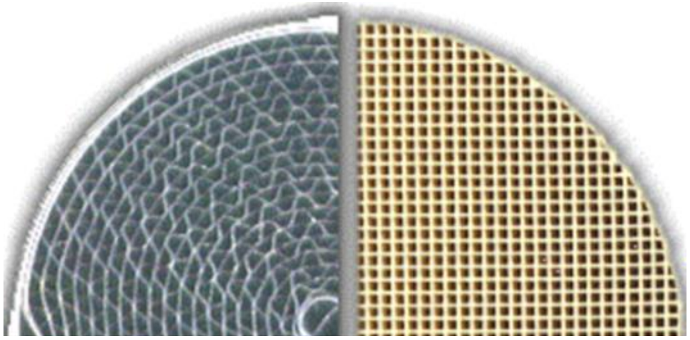


**Figure.5. Corrugated and Square cell shapes**

CFD was performed on corrugated and square shaped cells which are shown in Fig. 3.

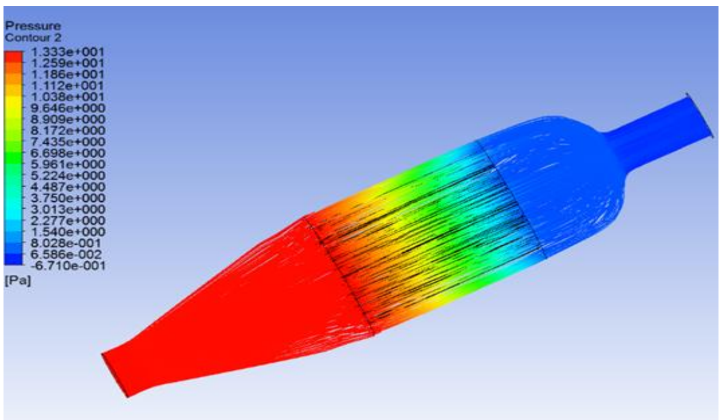



**Figure.6.CFD of square shaped substrate within the converter**


**Figure.7. CFD of corrugated shaped substrate within the converter**

Comparing the results of the CFD analysis, corrugated shaped substrate provided with 23% less pressure drop and better flow distribution. Also, corrugated shape exposes more surface area for catalyst coating which decreases the light-off period and activates the catalyst at a faster rate, resulting in less emissions and stable catalysis[9].

## VIII. EXPERIMENTAL ANALYSIS


**(a)**

**(b)**

**Figure.6. (a) Gas Analyzer , (b) Experimental Setup**

The engine was run on idling settings (1750 rpm) till a stable temperature of 250℃ was attained. This was measured using a calibrated K-type thermocouple. The engine emissions were measured on the Gas Analyzer shown in Figure 6. Four sets of readings were taken at varied engine speeds. Settling time of 30 seconds was provided for each set. Figure 7 & 8 represents HC and CO emissions at three engine speeds i.e. idling (1750), working speed (2800) and full throttle (3800).

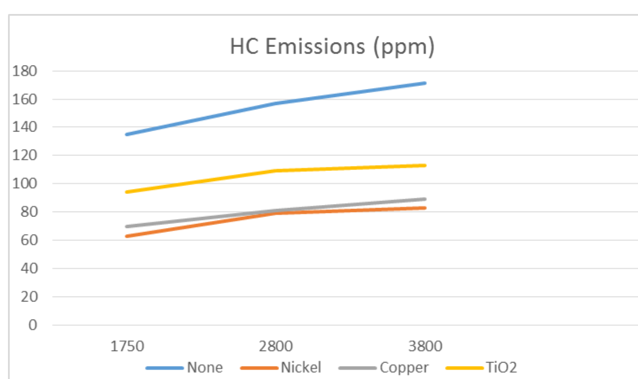



**Figure.7. HC emissions at different speeds wrt converter type**

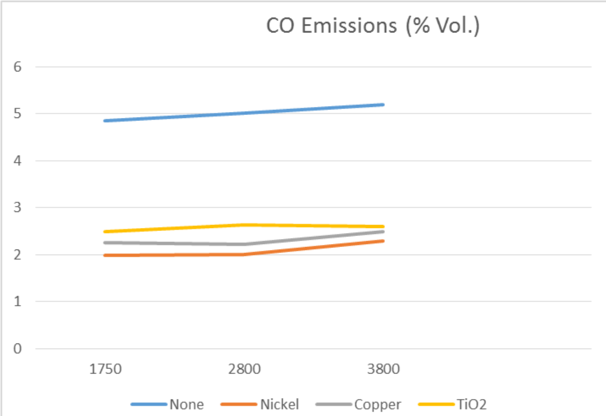



**Figure.8. CO emissions at different speeds wrt converter type**

Emissions were measured for three substrates integrated within the chamber. The results are presented in Table 1.

**Table.1. Emission results with respect to converter type**

| Sr. No | Substrate | HC Emissions (ppm) | CO Emissions (% Vol) |
|---|---|---|---|
| 1. | None | 135 | 4.85 |
| 2. | Nickel Coated monolith | 63 | 1.98 |
| 3. | Copper coated wire mesh | 70 | 2.25 |
| 4. | $TiO_2$ coated wire mesh | 94 | 2.5 |

From the emission values, percent reduction of each substrate from the engine exhaust emissions was calculated and is presented in Table 2 below.

**Table.2. Percentage reduction in emission with respect to converter type**

| Sr. No | Substrate | HC Reduction (%) | CO Reduction (%) |
|---|---|---|---|
| 1. | Nickel coated monolith | 51.85 | 59.17 |
| 2. | Copper coated wire mesh | 48.15 | 53.6 |
| 3. | $TiO_2$ coated wire mesh | 30 | 48 |

Nickel coated monolith substrate resulted in highest emission reduction consisting of 51.85% HC reduction and 59.17% CO reduction. Thus, it was selected as the catalyst for the catalytic converter.

## IX. CONCLUSION

In cold flow simulation, 100 CPSI with thin walls, showed the lowest pressure drop. Also, the designed geometry had the lowest eddies occurring in the converter. When compared with Copper as well as $TiO_2$, Nickel, which reduces 51.85 ±5.27 % of HC and 59.17 ±3.49 % of CO, was found to be the most suitable catalyst. Inlet cone angle of 15° lead to a pressure drop of 4 Pa.

## X. FUTURE SCOPE

A double corrugated structure is proposed for the monolith. Each single arm of the corrugation will be corrugated, which will result in a tri-corrugated cell. The effective surface area will increase keeping the CPSI the same.

## ANNEXURE

CPSI considered while modeling = 100

For corrugated structures, the area of the sheet per square inch are calculated using the given formula-

$y = 1.35\sin(0.589x)$ (3)

Amplitude of corrugation (x)= 2mm

$\therefore y = 1.35\sin(0.589 * 2)$

$\therefore y = 1.227\ mm$

Length of the hypotenuse formed by the triangle = $\sqrt{(2^2 + 1.277^2)}$

Approximate length of the corrugation curve = 4y

∴length=9.3855mm

Each single corrugation will host 4 / 3 double corrugated cells.

∴length of cell for this structure=12.467mm

% increase in the surface area = 34.24 %

From Computational Fluid Dynamic analysis performed on the various cell shapes gave the following results-

**Table.3. Change in turbulence, pressure drop & surface area with respect to substrate type**

| Substrate | Turbulence Eddy Dissipation | Pressure Drop (Pascal) | Effective Surface Area per Square Inch($mm^2$) |
|---|---|---|---|
| Square | 0.89 | 5.8 | 645.16 |
| Corrugated | 1.28 | 6.4 | 938.68 |
| Triangulations | 0.76 | 4.7 | 512.33 |
| Double Corrugated | 1.43 | 6.9 | 1234.47 |

### Manufacturing Processes

Corrugated sheets are produced using sheet rollers and a cam setup which oscillates, giving the corrugations of required frequency. A similar setup with multiple rollers and multiple cams can be used to provide a corrugation of a corrugated sheet with required frequency. Rolling these sheets into given dimensions to get required CPSI will give double corrugated monolith. Owing to some fabrication constraints, it was impractical to fabricate double corrugations.

### Statistics

Double corrugated sheets will give better turbulence leading to better heat-mass dissipation. The effective surface area will increase by 35% and it is proposed that the emission reduction will increase by 29%. Pressure drop increased by 13% as compared to single corrugated structure but was 11% less than 200 CPSI structure of same diameter.

**XI. REFERENCES**

[1].R. Bruck & W. Maus, Flow Improved efficiency by New Cell Structures in metallic substrates, SAE International Congress and Exposition, Detroit (1995).

[2].A.N. Marghmaleki, The Influence of geometry on the performance of catalytic converter, University of Alberta.

[3].Vinod M. Janardhanan & Olaf Deutschmann, Computational fluid dynamics of catalytic reactors, Indian Institute of Technology Hyderabad.

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

[5].H. Lian, P. Kerfriden, S.P.A. Bordas, Shape optimization directly from CAD: An isogeometric boundary element approach using T-splines.

[6].John N. Armor, "Materials Needs for Catalysts To Improve our Environment", Chem. Mater. 1994, 6, 730-738.

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

[8].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

[9].Julia Windmann, Peter Zacke "Impact of the Inlet Flow distribution on the Light off Behaviour of Three-way Catalytic Converter", Society of Automotive Engineers, 2002.

[10].Joachin Braun, Thomas Hauber,"3 Dimensional Simulation of the Transient Behaviour of a Three-way Catalytic Converter" Society of Automotive Engineers, 2002.

[11].Rolf Bruck, "Turbulent Flow Catalyst: Solution for EURO 5 & Beyond."