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# Study of Velocity and Pressure Distribution Characteristics Inside Of Catalytic Converter Geometry With Fluent 2D – Modeling & Simulation

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**ABSTRACT:**
*Catalytic Converters used in modern days Automobiles play a very important role towards reducing the harmful pollutants entering into our local environment. The efficiency of Catalytic converter solely depends upon the Geometry & Catalyst elements used. This paper reports the investigation made on two designs of Catalytic converter geometry namely Cylindrical & Convergent–Divergent shape. The Velocity & Pressure drop characteristics inside the converter have been described by using FLUENT 2D-Modeling flow through Porous media. GAMBIT was use as pre-processing tool for geometry creation & meshing.The detail study shows that the Cylindrical Catalytic converter creates more pressure drop as compared to the Convergent-Divergent shape and the NOx conversion efficiency is also high in the Cylindrical Catalytic converter. The simulation results of Velocity variation & Pressure drop characteristics in these two geometries are validated with the laboratory results.*

***KEYWORDS:*** *Catalytic Converter, DeNOx catalyst, Modeling & Simulation, Porous media, GAMBIT, FLUENT-CFD*

## I. INTRODUCTION

Air pollutants emitted from the Transport sector is the second largest source after the Industrial sector. Major pollutants emitted from Automobiles are CO, HC, NOx and PM (Smoke). 3-Way Catalytic converters are being used in Petrol driven vehicles for reducing these pollutants from the exhaust stream. After the invention of Catalytic converter by Eugen Haudry in the year 1930, much advancement is being done worldwide in the area of Catalytic Converter geometry, Catalytic elements, Catalyst types, Substrate material & Catalytic elements loading process over the substrate materials. Catalytic converter poses certain problems like back pressure which reduces engine efficiency, nonuniform flow, which reduces the Catalytic converter efficiency. Also the Catalytic material must be sufficient to treat the pollutants to meet the emission norms. As per the investigation made by Pannone et al [1] an Engine may loss about 300 W of power per 1000 Pa drop in pressure. Therefore, a trade-off between pressure drop & amount of catalyst or total catalytic surface area required has become the main concern for the geometry of Catalytic converters. Design optimization studies of automotive exhaust systems are carried out by Lakshmikantha *et al*. They optimized exhaust system design parameters such as shape and profile of manifold, catalyst inlet tube, inlet cone, exit cone, and exit tube under a given exhaust gas conditions.Amirnodin *et al* [3] adapted sub-grid scale modeling to predict the pressure loss of square cell shape of the honeycomb monolith structure for Catalytic converter. This sub-grid scale modeling represents the actual variation of pressure drop between the inlet and outlet for various combinations of wall thickness and cell density. The comparison is being made to the experimental and numerical work establish in the literature. The sub-grid scale modeling gives better agreement in pressure drop compared to the numerical work using single channel approach.

Subramanyeswararao (2014) has investigated the effect of geometric parameters on the performance of automotive catalytic converters. He has studied the effect of fluid flow due to geometry change by using FLUENT 6.0. The increase in inlet cone angle increases the vorticity of the flow, which leads to inactive zones and increase inlet cone length reduces the recirculation zones. Back pressure decreases as angle of the inlet cone decreases upto 300 and diameter of substrate increases. The exhaust emission decreases with the increases with the increase in catalyst diameter and increase in catalyst length [4]. Patil, et *al* (2013) has focused on reducing the back pressure in the exhaust system to increase the combustion efficiency by using FLUENT CFD. In CFD analysis various diffuser models with different angles were simulated by using appropriate boundary conditions and fluid properties [5]. Karuppuswamy *et al* (2013) in their study aimed for more filtration efficiency with limited back pressure. They have simulated various models with different wire mesh grid size using the appropriate boundary conditions and fluid properties. Through CFD analysis, the vorticity and back pressure of various models were studied. The increase in inlet cone angle increases vorticity of flow, which leads to inactive zone and reduces the back pressure. They have also found that installation of catalytic converter reduces the back thermal efficiency and increases the brake specific fuel consumption and fuel flow rate [6].K. Mohan Laxmi *et al* (2013) has studied the effect of change in inlet fluid (Nitrogen gas) velocity on the pressure & the velocity distribution inside the catalytic converter [7].

## II. GEOMETRY

The two designs of Catalytic converter for the study are as shown below:

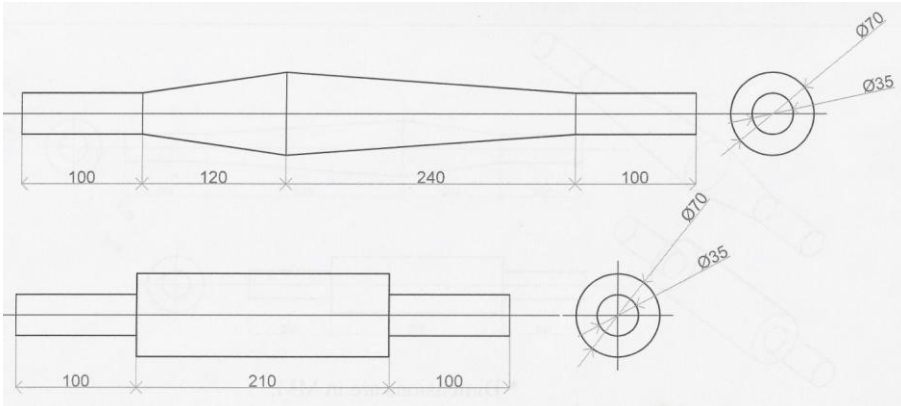


Fig 1 Catalytic converter drawing (All dimensions are in mm)

Fig 2 Actual Catalytic converters (Cylindrical & Convergent-Divergent shape)

## III. CFD SIMULATION BY FLUENT

The 2D model of these catalytic converters is modeled by using GAMBIT which is a preprocessor for FLUENT. The quadrilateral mapped mesh is generated and the mesh is examined for its quality. After examining the mesh quality, the FLUENT 5/6 solvers are chosen and the boundary type conditions and continuum conditions are given. Then the boundary zone assigned model is exported as the 2D mesh file.

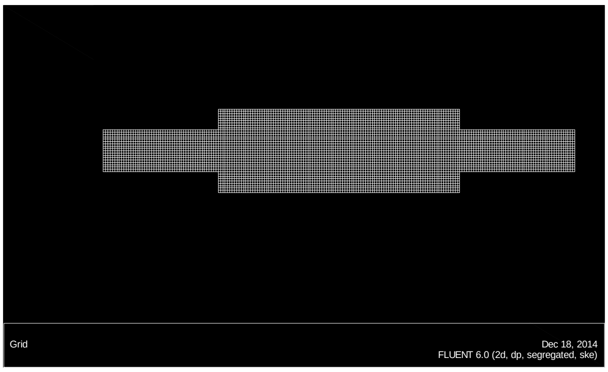


Fig 3 2D- Mesh file of Cylindrical Catalytic Converter

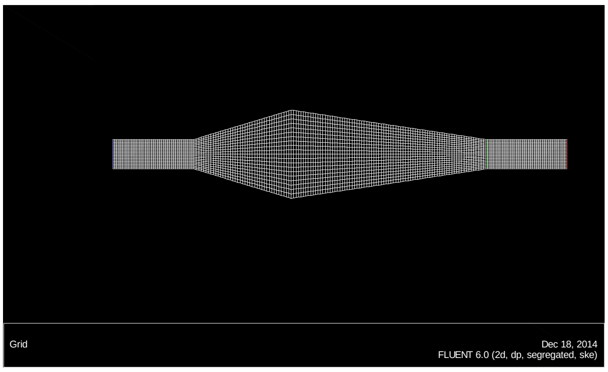


Fig 4 2D- Mesh file of Con-Div Catalytic Converter

A 2D segregated solution method, implicit solution formulation and a steady state flow is opted with absolute velocity formulation. The standard *k*-□ model is selected under the viscous model for the turbulent flow calculation with the standard wall function as the near wall treatment. The energy equation is enabled. The fluid medium is assumed as Nitrogen because it dominates in the vehicular exhaust. The properties of Nitrogen are given in table 1. The inlet velocity is set as 30 m/sec and temperature 300K. The intensity and hydraulic diameter are set for the turbulence specification method and the turbulence intensity is taken as 5. At the outlet the pressure is set as 0 gauge pressure. The substrate region is treated as the laminar and porous zone. The viscous & inertial resistance values of porous material are given as in table 2 and boundary conditions are given in table 3.

Convergence is being done using absolute criterion of 1e-5. Solution methods-Spatial discretization, Gradient- least square cell based, Pressure-standard, Momentum. Turbulent kinetic energy and turbulent dissipation rate are taken at second order upwind, Surface monitors report with respect to mass flow rate at outlet and solution is initialized & computed from exhaust gas inlet. Solution is run for 200 iterations. It was seen that the solution converge at about 90-160 iterations.The porous region is first considered as empty and then filled (i.e. Porous not applied and applied). At 30 m/s fluid (Nitrogen) velocity simulation is done for these two cases. Velocity and Pressure contours are created as well as X-Y plots are generated at the axis.

Table 1 Fluid (Nitrogen) properties

| | |
|---|---|
| Density | 1.136 Kg/$m^3$ |
| Viscosity | 1.663 e-$^{05}$ Kg/m-s |

Table 2 Porous media properties

| | Viscous resistance (1/$m^2$) | Inertial resistance (1/m) |
|---|---|---|
| Direction 1 | 3.846e$^{+07}$ | 20.414 |
| Direction 2 | 3.846e$^{+10}$ | 20414 |

Table 3 Boundary conditions

| Boundary | Assigned as |
|---|---|
| Inlet | Velocity Inlet |
| Outlet | Pressure Outlet |
| Wall | Wall |

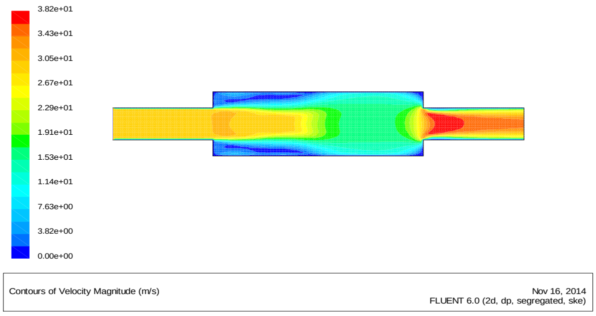


**Fig 5 Velocity contour: Cylindrical Cat Con (Empty)**

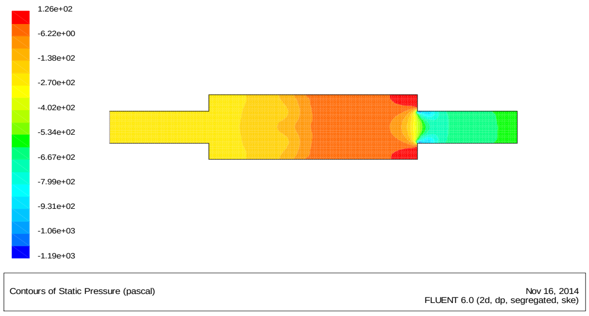


**Fig 6 Pressure contour: Cylindrical Cat Con (Empty)**

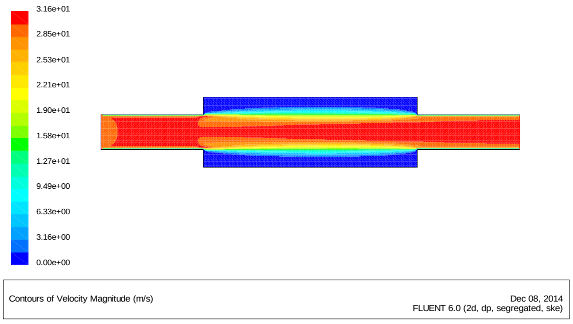


**Fig 7 Velocity contour: Cylindrical Cat Con (Filled)**

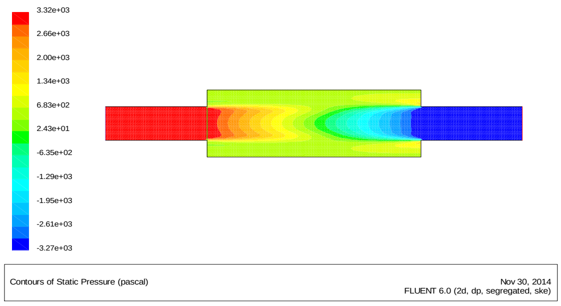


**Fig 8 Pressure contour: Cylindrical Cat Con (Filled)**

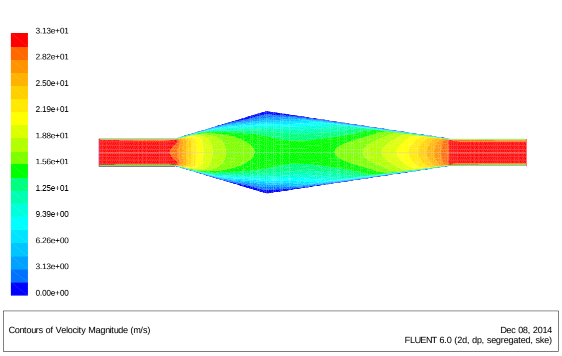


**Fig 9 Velocity contour: Cov-Div Cat Con (Empty)**

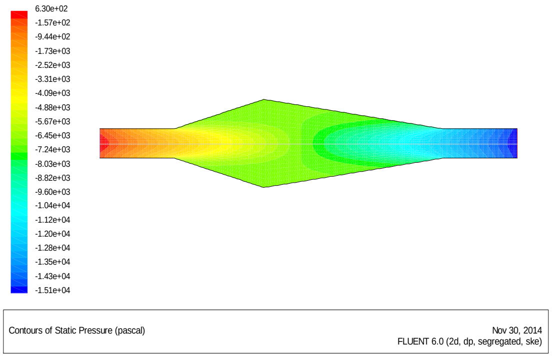


**Fig 10 Pressure contour: Con- Div Cat Con (Empty)**

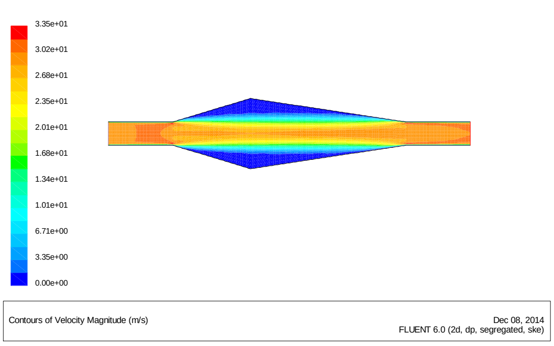


**Fig 11 Velocity contour: Con-Div Con (Filled)**

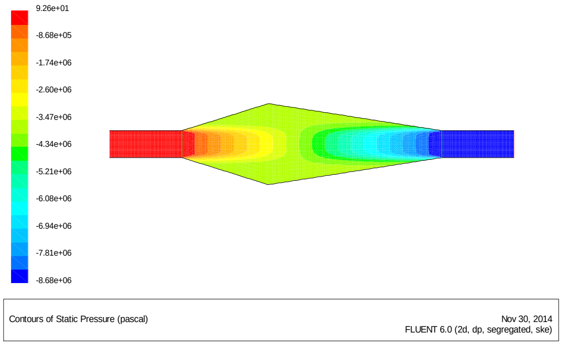


**Fig 12 Pressure contour: Con-Div Cat Con (Filled)**

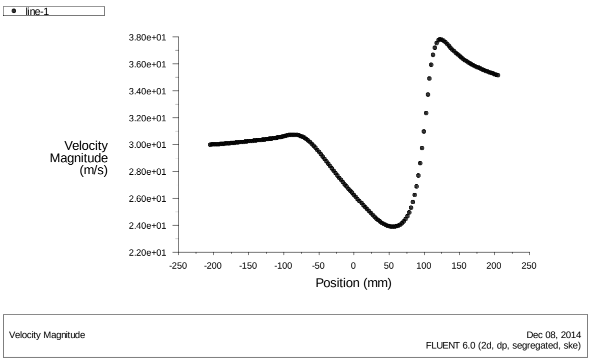


**Fig 13 Velocity magnitude: Cylindrical (Empty)**

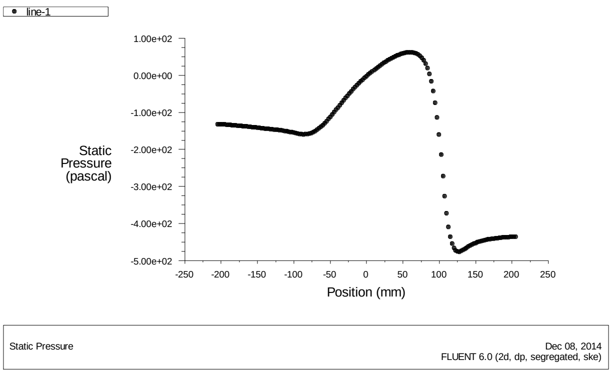


**Fig 14 Static Pressure: Cylindrical (Empty)**

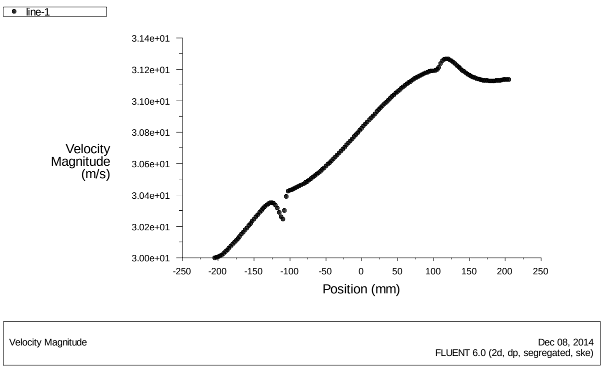


**Fig 15 Velocity magnitude: Cylindrical (Porous)**

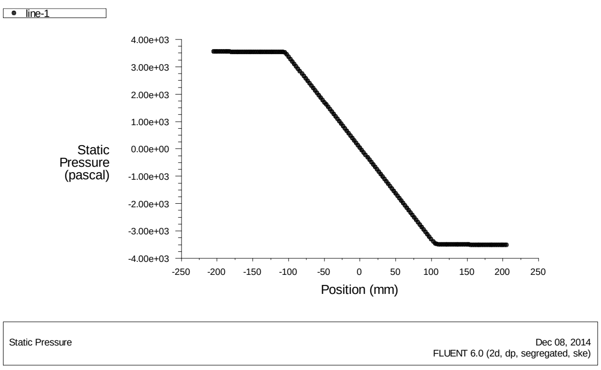


**Fig 16 Static Pressure: Cylindrical (Porous)**

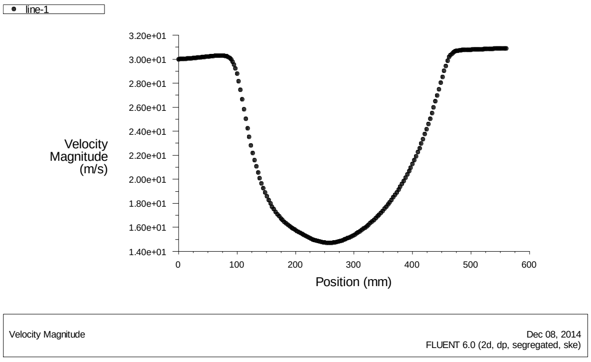


**Fig 17 Velocity magnitude: Con-Div (Empty)**

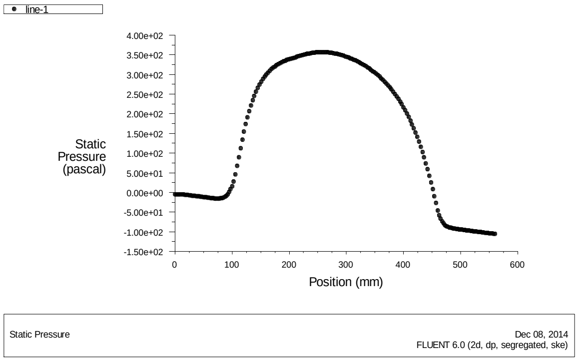


**Fig 18 Static Pressure: Con-Div (Empty)**

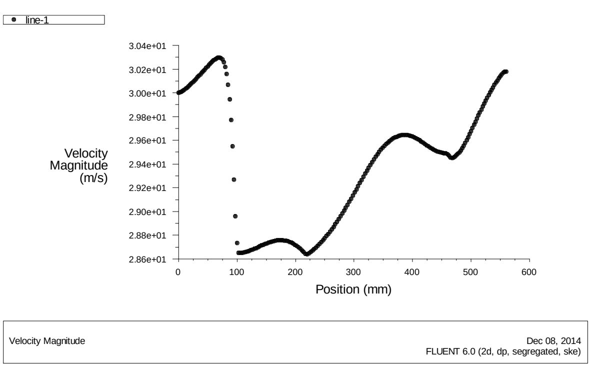


**Fig 19 Velocity magnitude: Con-Div (Porous)**

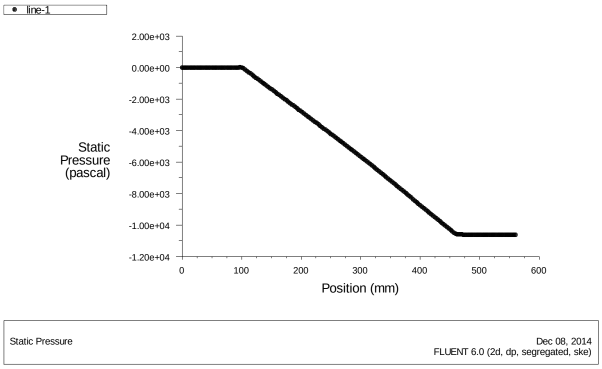


**Fig 20 Static Pressure: Con-Div (Porous)**

## IV. EXPERIMENTAL VALIDATION

To validate experimentally, the pressure drop variation in these two designs of Catalytic converters, an experimental setup is created which has an air compressor. The Catalytic converter empty and filled with catalyst pellets were fitted alternately to the air outlet having a control valve. Air velocity was fixed to 30 m/s with the help of this control valve. Air velocity was measured by a vane type anemometer. 2" long and ¼" diameter copper tubes were soldered at the three locations of the catalytic converter body; one at entry, one at the middle and another at the exit of porous zone. The pressure drop was measured with the help of a glass U-tube manometer in terms of *mm of water column* and thereafter the pressure drops were converted into *Pascal*. The Simulation & Experimental results are tabulated in table 4 and table 5.

Table 4: Simulation Result of Empty & Filled Catalytic Converter

| Empty | | | | | Porous | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cylindrical | | Convergent-Div | | | Cylindrical | | Convergent-Div | |
| | V (m/s) | Δp (Pa) | V (m/s) | Δp (Pa) | | V (m/s) | Δp (Pa) | V (m/s) | Δp (Pa) |
| In | 30 | -150 | 31 | -25 | In | 30.4 | 3500 | 30.3 | 0 |
| Mid | 26 | 50 | 15 | 350 | Mid | 30.7 | 0 | 29.0 | -500 |
| Out | 38 | - 450 | 31 | -100 | Out | 31.3 | -3500 | 31.1 | -1000 |

Table 5: Experimental Result of Empty & Filled Catalytic Converter

| Empty | | | | | Porous | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cylindrical | | Convergent-Div | | | Cylindrical | | Convergent-Div | |
| | V (m/s) | Δp (Pa) | V (m/s) | Δp (Pa) | | V (m/s) | Δp (Pa) | V (m/s) | Δp (Pa) |
| In | 30 | -141 | 30 | 0 | In | 30.0 | 3360 | 30.0 | 0 |
| Mid | - | - 40 | - | 380 | Mid | - | 0 | 0 | - 410 |
| Out | 33 | - 410 | 27 | -130 | Out | 29.5 | -3410 | 28.4 | - 960 |

## V. CONCLUSION

From the result Table 4 and Table 5; it is seen that the Simulation & Experimental results are validated within narrow limits. It can also be concluded that the cylindrical catalytic converter has more pressure drop as compared to the Convergent-Divergent Catalytic converter. Therefore, the residence time, i.e. reaction time for pollutant with the Catalyst will be more. Thereby, the cylindrical catalytic converter is more effective for pollutant reduction from the exhaust stream of any vehicle. The authors have also conducted experiments with their own prepared catalyst. We have prepared and tested 5% Silver & 5% Iron loaded catalysts over γ-Alumina support and tested in the exhaust stream of Jeep (M &M make). The converters were heated externally by an electrical heating tape at temperature of $280^0$C. The maximum NO conversion of 36.36% achieved under full acceleration with the cylindrical catalytic converter. When the experiment was conducted in Convergent-Divergent catalytic converter filled with 5% Silver catalyst the NO conversion slightly reduces to 31.41%. This is because the convergent-divergent shape gives less resistance in the flow of exhaust gases and consequently, the residence time is less for the reaction of nitric oxide gas with catalyst.Similarly, when 5% Iron catalyst was tested in cylindrical catalytic converter the NO conversion was 27.08% and with Convergent-Divergent catalytic converter it was 25.25%. Graphical representations of the NO conversion efficiency of 5% Silver & 5% Iron catalysts with Cylindrical & Convergent-Divergent catalytic converter is shown in Fig 21.

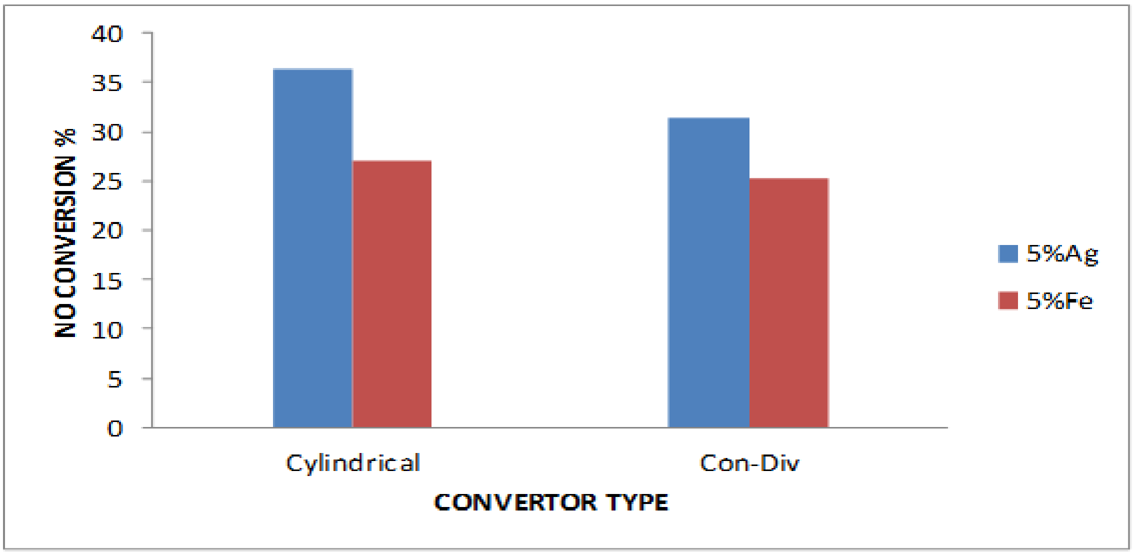


Fig 21: Type of catalytic converter V/s NO conversion%

## VI. ACKNOWLEDGEMENTS

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