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*Full Length Research Paper*

# Optimum solution of catalytic converter with filtration efficiency of trap system by developing limited back pressure in diesel engine

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**Now a days the global warming and air pollution are big the issues in the world. The 70% of air pollution is due to emissions from an internal combustion engine. The harmful gases like , $NO_X$, CO, unburned HC and particulate matter increases the global warming. So catalytic converter plays a vital role in reducing harmful gases and hence analysis of catalytic converter is very important in the study of diesel engines. The rare earth metals now used as catalyst to reduce $NO_X$ are costly and rarely available. The scarcity and high demand of present catalyst materials necessitate the need for finding out the alternatives. Among all other particulate filter materials in the present study knitted steel wire mesh material is selected as filter material and the optimum analyzation to get maximum filtration efficiency with limited back pressure developed inside the exhaust manifold is investigated. Through CFX technique, various models of catalytic converters with different wire mesh grid size combinations were simulated using the appropriate boundary conditions and the specified and suitable fluid properties are assumed to the system. Further comparison of back pressure of different catalytic converter models is made in the present paper.**

**Keywords:** Diesel particulate, catalytic filter, catalytic oxidation, pollutant reduction, exhaust emission, CFX.

## INTRODUCTION

Internal Combustion engines generate undesirable emissions during the combustion process, which include, $NO_X$ CO, unburned HC, smoke etc. Apart from these unwanted gases, it produces Particulate Matter (PM) such as lead, soot. All these pollutants are harmful to environment and human health. They are the main causes for greenhouse effect, acid rain, global warming etc. The simplest and the most effective way to reduce $NO_X$ and PM, is to go for the after treatment of exhaust. Devices developed for after treatment of exhaust emissions includes thermal converters or reactors, traps or filters for particulate matters and catalytic converters. The most effective after treatment for reducing engine emission is the catalytic converter found on most automobiles and other modern engines of medium or large size.

With the help of CFD analysis, it is attempted to find out the optimum solution to get maximum filtration efficiency with limited back pressure developed inside the catalytic converter.

In this regard many researchers were worked by considering different aspects like selection of filter material, choosing of meshing size, different thermal converters, reactors and catalytic converters.

Andreassi et al. (Muthaiah et al., 2010) investigated about the role of channel cross-section shape on mass

### Abbreviations

CFD – Computerized Fluid Dynamics; $NO_X$ – Oxides of Nitrogen; PM – Particulate Matter; DOC – Diesel Oxidation Catalyst; MC – Mesh configuration; CPSI – Cells per Square Inch

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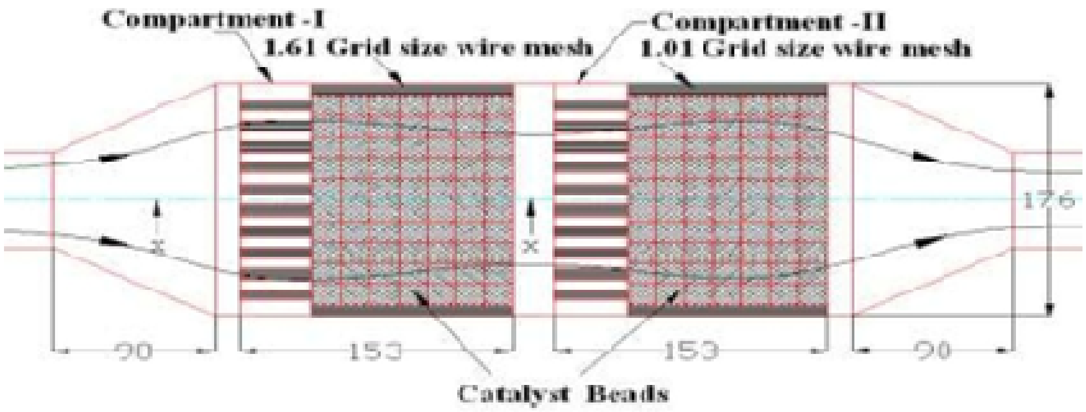


**Figure 1.** Catalytic converter Showing Two Compartments

and heat transfer processes. The development of catalytic converter systems for automotive applications is, to a great extent, related to monolith catalyst support materials and design. They also studied improvements of converter channels fluid-dynamics aiming to enhance pollutant conversion in all the engine operating conditions. Rajadurai et al. (Kamble and Ingle, 2008) studied the effect of Knitted wire mesh substrates with different geometry and channels on the back pressure of catalytic converter. They considered primary requirements of exhaust after treatment systems of low back pressure, low system weight, better emission performance and lower cost. Combinations of these properties provide better engine performance and higher system value. Ekstrom and Andersson (Beardsley et al., 1999) analysed about the pressure drop behavior of catalytic converter for a number of different substrates, suitable for high performance IC-engines, regarding cell density, wall thickness and coating. The data has been used to develop an empirical model for pressure drop in catalytic converters. An investigation has been carried out for reducing pollutants from a variable compression ratio, copper-coated spark ignition engine fitted with catalytic converter containing sponge iron catalyst run with gasohol by Narsimha et al. (Eberhard et al., 2005). Mohiuddin and Nurhafez (Jacobs et al., 2006) conducted an experiment to study the performance and conversion efficiencies of ceramic monolith three-way catalytic converters (TWCC) employed in automotive exhaust lines for the reduction of gasoline emissions. Muthaiah et al. (Lahousse et al., 2006) conducted an experimental test on a 10 hp, twin-cylinder, and four-stroke, direct-injection, vertical diesel engine. At present, the wall flow ceramic substrate is used as filters which are expensive and also offer more back pressure resulting in more fuel consumption.

Motivated by the above studies in the present paper catalytic-coated steel wire mesh materials with coarse, fine, and very fine grid sizes are used for PM filtration. The soluble organic fractions of diesel PM is oxidized by DOC system which provides strong motivation for the development of improved catalytic converter.

### Selection of Filter Material

There are many types of filter materials are used in internal combustion engine. They are Ceramic monolith, ceramic foam, steel wire meshes, ceramic silicon fiber, porous ceramic honey comb are the few types of filter materials. Out of these filter materials, steel wire mesh is selected as filter material because knitted steel wire mesh material is ranked first for its collection efficiency of particulate matter. The other reasons for its selection are,

- Thermal stability during regeneration.
- Good mechanical properties.
- Long durability.
- Easy availability and less cost

### Construction

The catalytic converter consist of

- Inlet duct
- Inlet conical potion
- First compartment
- Second compartment
- Outlet conical portion
- Outlet duct

The beads are designed so that the top and bottom portions are open and the gas can go up and down to the next layer of beads through the steel wire mesh layers which are also horizontally placed.(Figure 1, 2, 3 and 4)

### Wiremesh Specifications

In this analysis, the selected steel wire mesh grid sizes

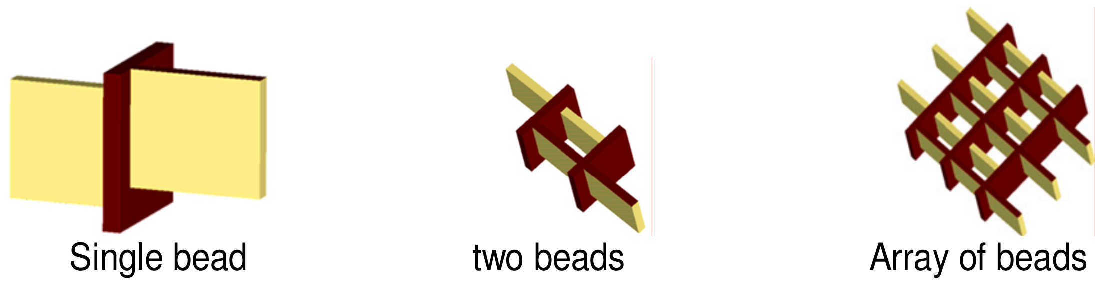


**Figure 2.** Bead description.

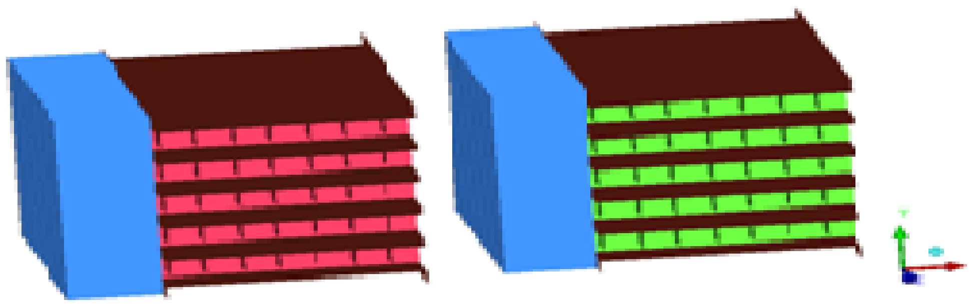

**Figure 3.** Catalytic converter showing 1st and 2nd compartment.

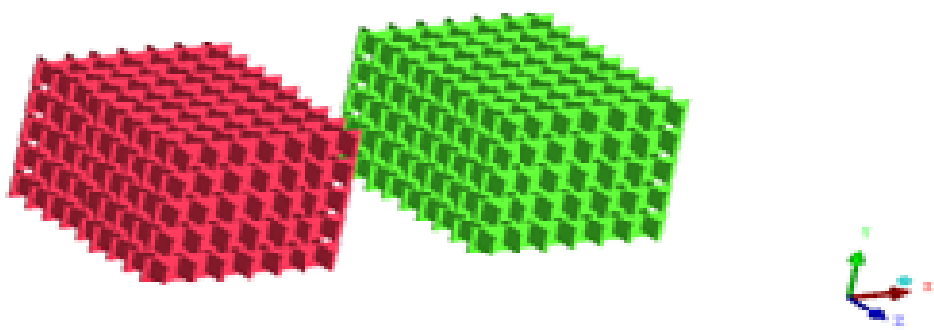

**Figure 4.** Catalyst beads showing in 1st and 2nd compartment.

are 1.96, 1.61, 1.01 and 0.65 mm. The specifications of these wire meshes are shown in Table 1. Three models are made, each using two different grid size wire meshes placed in two separate compartments. The details of wire mesh grid sizes used in different models are shown in Table 2.

## Working Principle

In the first compartment the exhaust gas passes through catalytic beads and steel wire mesh material which are coated with metal catalyst. As the hot gases contact the catalyst and the coated wire mesh, most of the exhaust pollutants such as CO, gaseous hydrocarbons, and unburned fuel and lube oil, toxic aldehydes etc. are oxidized to $CO_2$ and water, thus reducing harmful emissions. In the second compartment ammonia plus exhaust gas is passed through catalytic beads and steel wire mesh material which are coated with metal catalyst. Ammonia derived from urea is used to reduce $NO_X$ from diesel engines. Ammonia is produced on-board by rapid hydrolysis of nonhazardous form of urea solution. In second compartment the $NO_X$ are converted into nitrogen and oxygen.

In both compartments a part of the exhaust gas passes through the wire mesh layers which trap a portion of the soot. The remaining exhaust gas flows out to the neighboring bead placed in the same line – similar to a flow-through substrate. The soot trapped in the wire mesh material is combusted by the $NO_2$ that is generated by the upstream catalyst and thus the filter is regenerated continuously. If a situation occurs where filter regeneration is stopped and a saturation point occurred

Table 1. Provide legend.

| Sl. No. | Wire mesh/ gap size (mm) | Wire diameter (mm) | Open area/ porosity (%) | Weight (kg/m$^3$) | Mesh per inch | Cells per square inch | Viscous resistance [ x 10^7](1/m$^2$) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Normal | Transverse |
| 1 | 1.96 | 0.58 | 59.3 | 1.71 | 10 | 100 | 3.846 | 3846 |
| 2 | 1.61 | 0.51 | 57.7 | 1.56 | 12 | 144 | 4.286 | 4286 |
| 3 | 1.01 | 0.41 | 50.8 | 1.51 | 18 | 324 | 6.086 | 6086 |
| 4 | 0.65 | 0.25 | 51.8 | 0.92 | 28 | 576 | 8.606 | 8606 |

Table 2. Provide legend.

| Model name | Wire mesh grid size in compartment 1 (mm) | Wire mesh grid size in compartment 2 (mm) |
|---|---|---|
| MC-1 | 1.96 | 1.61 |
| MC-2 | 1.61 | 1.01 |
| MC-3 | 1.01 | 0.65 |

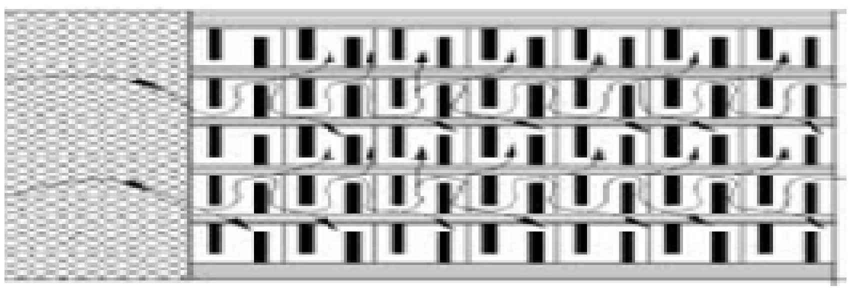

**Figure 5.** The path of exhaust gas in catalytic converter

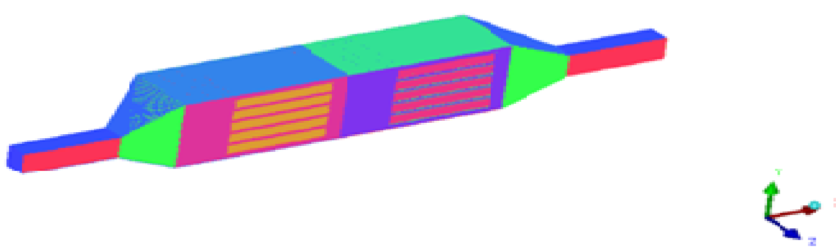

**Figure 6.** The meshed catalytic converter model

with the collected soot, the wire meshes placed over the catalytic beads will not plug as happened in wall flow filter. As the path of the gas is not totally blocked, the back pressure developed inside the catalytic converter is very much limited and no further increase in back pressure can happen beyond certain limit, irrespective of the soot loading over a period of time. A compressed air cleaning process is suggested to clean the PM deposition on steel wire meshes and catalytic beads. In this process, two numbers of compressed air inlet points are placed in between two compartments at diametrically in opposite position.(Figure 5)

## Modeling And Meshing

The geometry of catalytic converter is modeled and meshed in ICEM CFD. And the flow equations solved in ANSYS FLUENT.(Figure 6)

## Domain Conditions

The continuity and 3-dimensional momentum equations will be solved for the isothermal flow modeling. Turbulence will be modeled by $k$-ε RNG turbulence model appropriate to account for high velocities and strong

Table 3. Provide legend.

| Property | Air |
|---|---|
| Density (kg/m$^3$) | 0.7532 |
| Viscosity (Pa.s) | 3.0925 x $10^{-5}$ |
| Specific heat (J/kg-K) (not used) | 1056.6434 |
| Thermal conductivity (W/m-K) (not used) | 0.0242 |

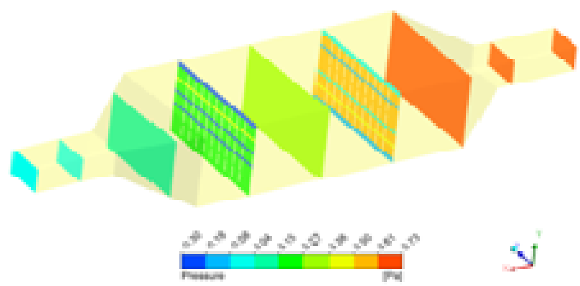

**Figure 7.** Pressure contour

streamline curvature in the flow domain. The reference pressure will be set at 1.33 atm and all pressure inputs and outputs will be obtained as gauge values with respect to this.

## MATERIAL

Air will be the working fluid considered to be operating at 350 $^0$C and 1.35 bar. The material properties under these conditions are: (Table 3)

## Boundary Conditions

The engine selected for this study is a four stroke twin cylinder (80mm bore and 110mm stroke length) water cooled diesel engine. The engine displacement is calculated as 552.64 cm$^3$ for the assumed vehicle speed of 60 m/s. The operating pressure will be maintained at 1.33 atm. The outlet will be considered as a pressure outlet at zero gauge pressure. A high turbulence intensity of 10% will be flow will be assumed for the inlet while the hydraulic diameter at the inlet will be considered to close the turbulence model equations.

## METHODOLOGY

A single phase single-species incompressible flow simulation with Air as the working fluid will be carried out.

The pressure drop or back-pressure will be tested for three sets of wire mesh configurations in the two compartments defined as MC-1, MC-2 and MC-3 for catalytic converter 80 mm.

## RESULTS AND DISCUSSION

We have considered the steel wire mesh configuration for all three models of catalytic converter having conical portion length as 80 mm MC-1, 80 mm MC-2, and 80 mm MC-3 respectively. The main aim of this investigation is to find out the right size of the filter material for the exhaust manifold which can offer minimum back pressure with maximum filteration efficiency of particulate matter PM ,using new catalyst for NOx reduction.

It is observed that the back pressure in MC-1, MC-2, MC-3 are found to be .6903, .7062 and .7074 bar respectively.The back pressure variations are represented through graphs in the following Figures 9,12 and 15.

Catalytic converter – 80 mm – MC-1 (Figure 7, 8 and 9).
Catalytic converter – 80 mm – MC-2 (Figure 10,11 and 12).
Catalytic converter – 80 mm – MC-3 (Figure 13, 14 and 15).

## COMPARISION OF THREE MODELS OF CATALYTIC CONVERTER 80mm MC-1, MC-2 AND MC-3

After comparing all the three models of catalytic converter it is found that, The catalytic converter 80mm– MC -1 has the lowest pressure drop or back pressure.(Figure 16)

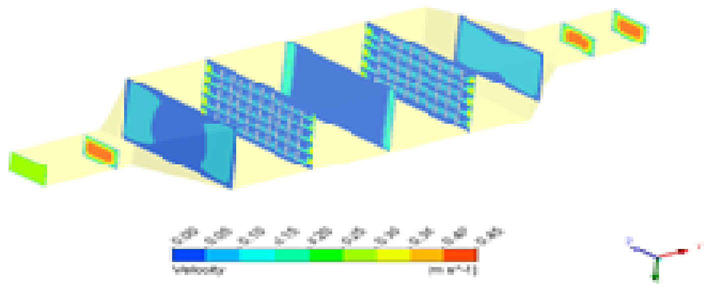

**Figure 8.** Velocity contour.

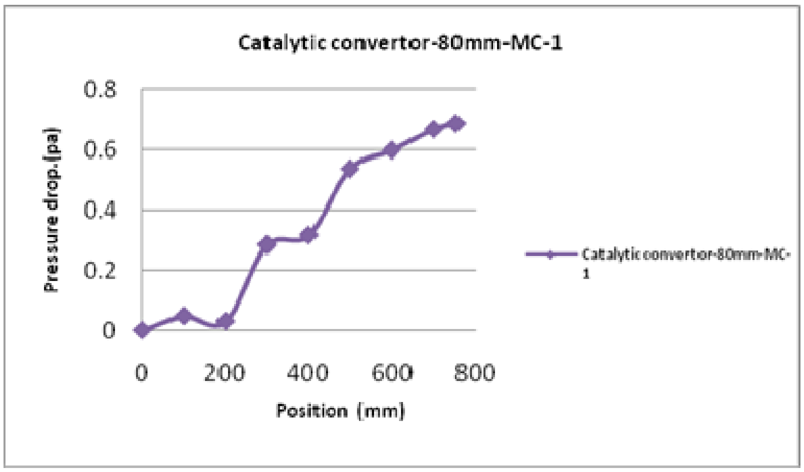


**Figure 9.** Provide legend.

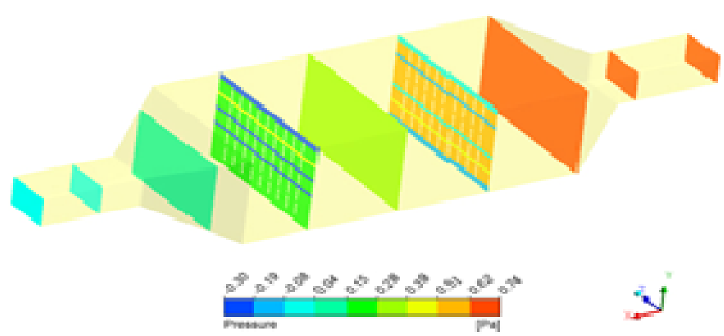

**Figure 10.** Pressure contour.

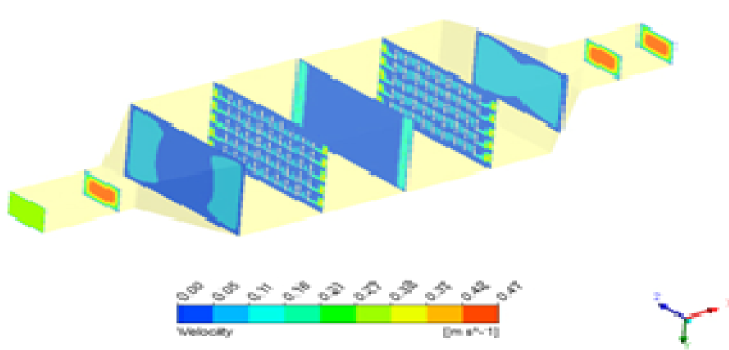

**Figure 11.** Velocity contour.

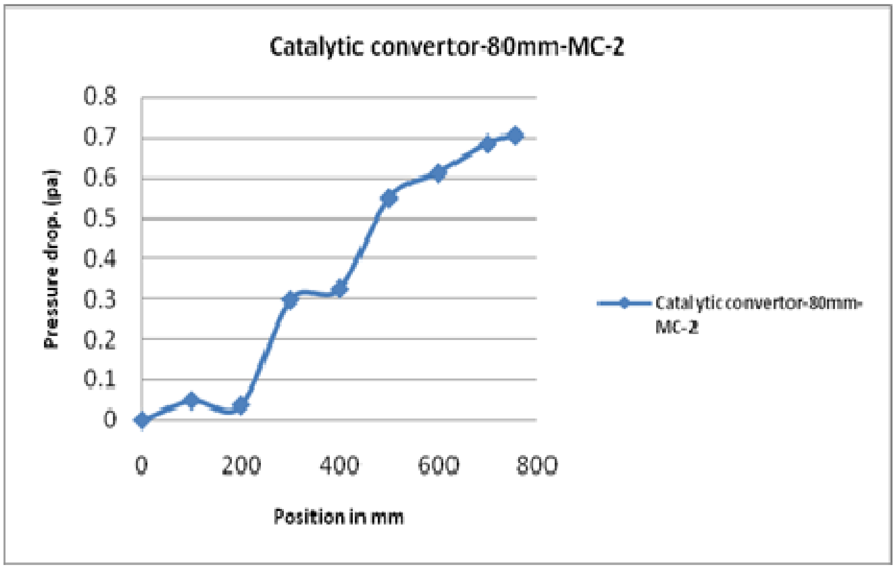


**Figure 12.** Provide legend.

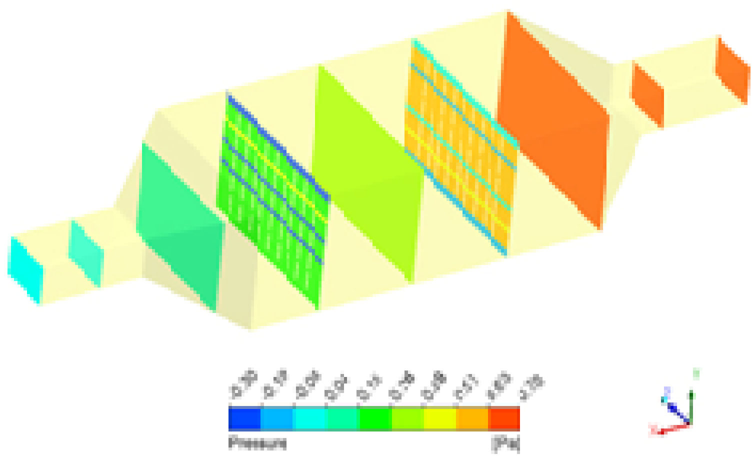


**Figure 13.** Pressure contour.

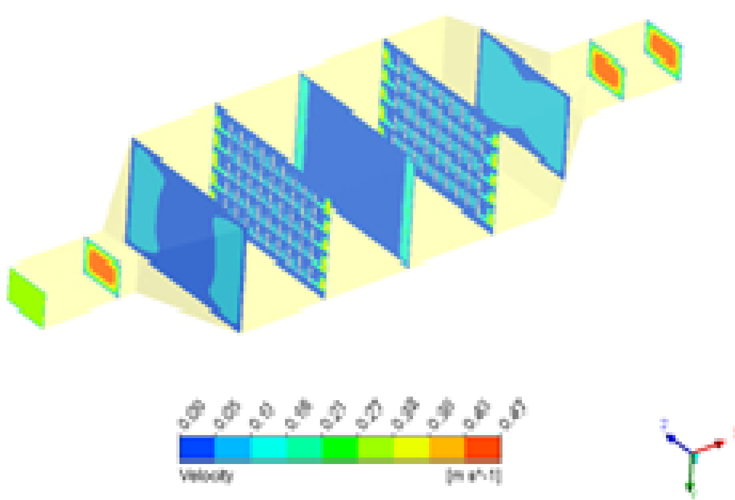


**Figure 14.** Velocity contour.

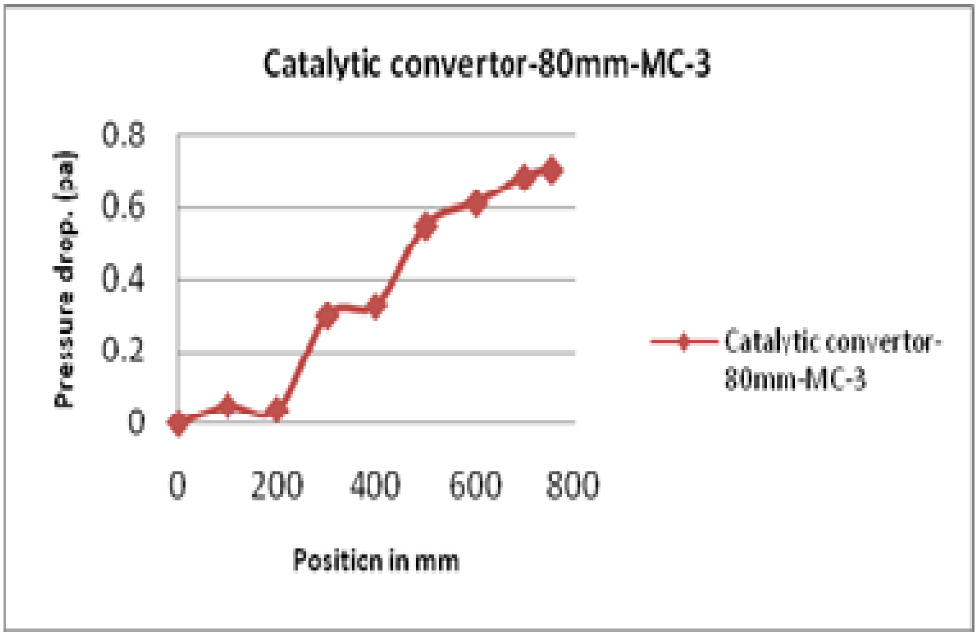


**Figure 15.** Provide legend.

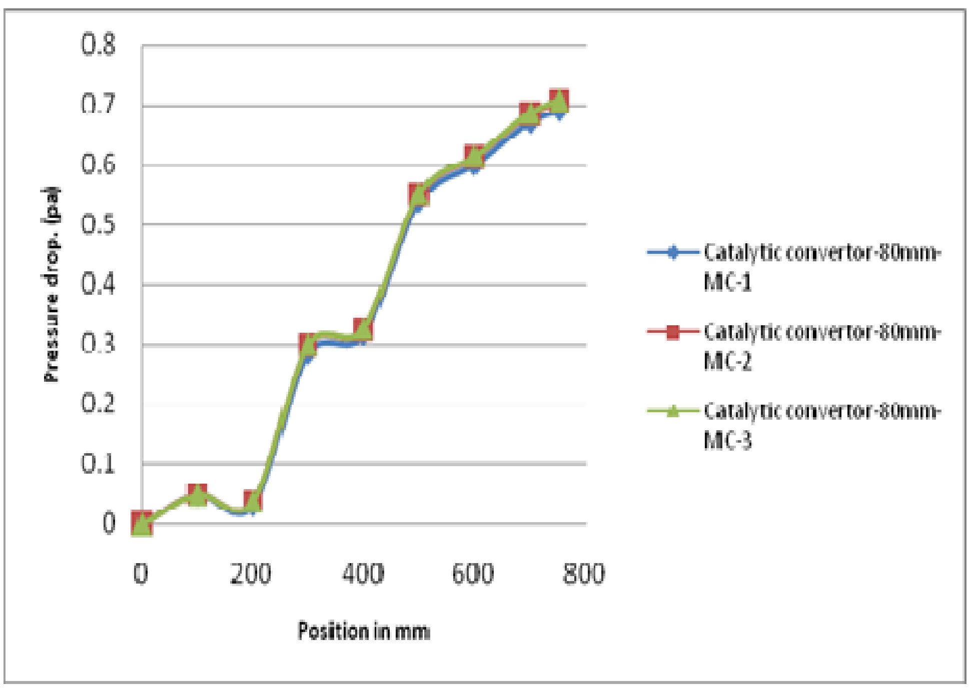


**Figure 16.** Provide legend.

## CONCLUSIONS

It is concluded that the catalytic converter 80mm-MC-1 has the lowest pressure drop or back pressure

- After comparing the catalytic converter with different conical portion length for same boundary condition, we can save the material required for manufacturing the catalytic converter at the same time we can save the cost for manufacturing catalytic converter.
- The special shaped catalytic beads allow the exhaust gas to flow freely without making any obstruction or blocking. It helps to limit the back pressure to the minimum level resulting in better engine performance and fuel saving.

- The catalytic beads are very hard, no wear and tear of catalyst can take place, and hence long life of catalyst is assured.

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