

## Design Analysis of Catalytic Converter to reduce Particulate Matter and Achieve Limited Back Pressure in Diesel Engine By CFD

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### ABSTRACT

Now a days the global warming and air pollution are big issue in the world. The 70% of air pollution is due to emissions from an internal combustion engine. The harmful gases like  $\text{NO}_x$ , CO, unburned HC and particulate matter increases the global warming, so catalytic converter plays an vital role in reducing harmful gases, but the presence of catalytic converter increases the exhaust back pressure due to this the volumetric efficiency will decrease and fuel consumption is higher. So analysis of catalytic converter is very important.

The rare earth metals now used as catalyst to reduce  $\text{NO}_x$  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, knitted steel wire mesh material is selected as filter materials in this paper. Through CFD analysis, various models with different wire mesh grid size combinations were simulated using the appropriate boundary conditions. The comparison of back pressure of different catalytic converter models is made in this paper.

### 1. INTRODUCTION

Internal Combustion engines generate undesirable emissions during the combustion process, which include,  $\text{NO}_x$ , 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  $\text{NO}_x$  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.

The catalyst and filter materials placed inside the catalytic converter increase back pressure. This increase in back pressure causes more fuel consumption, and in most cases, engine stalling

might happen. The filtration efficiency and back pressure are interrelated. If maximum filtration efficiency using very fine grid size wire meshes, is achieved, the back pressure will also be increased, which causes more fuel consumption. On the other hand, if larger grid size wire meshes are used, back pressure will be less, but the filtration efficiency will also be reduced, which does not help in meeting the present emission norms. 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.

Andreassi et al. [1] investigated the role of channel cross-section shape on mass 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. In this paper improvements of converter channels fluid-dynamics aiming to enhance pollutant conversion in all the engine operating conditions are studied. Rajadurai et al. [2] investigated the effect of Knitted wire mesh substrates with different geometry and channels on the back pressure of catalytic converter. The primary requirements of exhaust after treatment systems are low back pressure, low system weight, better emission performance and lower cost. Combinations of these properties provide better engine performance and higher system value. Combinations of these properties provide better engine performance and higher system value Ekstrom and Andersson [3] Investigated 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 measurements have been performed on an experimental rig with room-air flow and hot-air flow. The data has been used to develop an empirical model for pressure drop in catalytic converters. Narasimha Kumar et al. [4] Investigations have 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 (blend of 20% ethanol and 80% gasoline by volume). The major pollutants emitted from spark ignition engine are carbon monoxide

(CO) and unburnt hydrocarbons (UHC). Mohiuddin and Nurhafez [5] 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. Two ceramic converters of different cell density, substrate length, and hydraulic channel diameter and wall thickness were studied to investigate the effect of varying key parameters on conversion efficiencies and pressure drop.

Muthaiah et al. [6] 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. In the present study, 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. So this provides strong motivation for 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

## 2. CONSTRUCTION

The catalytic converter consist of

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

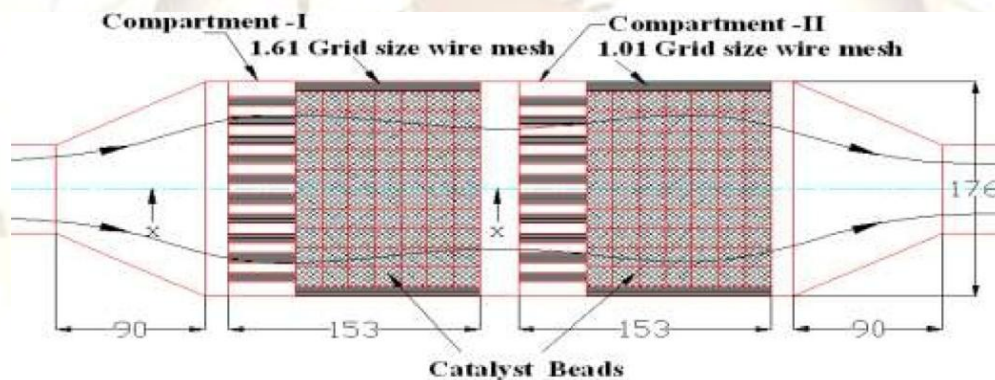


Fig-1: catalytic converter Showing Two Compartments



Fig-2: Bead description

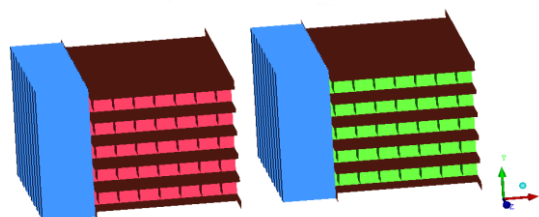


Fig-3: catalytic converter showing 1<sup>st</sup> and 2<sup>nd</sup> compartment.

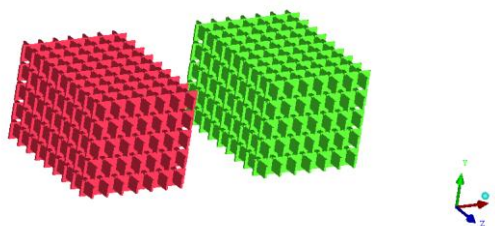


Fig-4: catalyst beads showing in 1<sup>st</sup> and 2<sup>nd</sup> compartment.

### 3. WIREMESH SPECIFICATIONS

S. No.	Wire mesh/gap size (mm)	Wire diameter (mm)	Open area/porosity (%)	Weight (kg/m <sup>3</sup> )	Mesh per inch	Cells per square inch	Viscous resistance [ x 10 <sup>7</sup> ](1/m <sup>2</sup> )	
							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

Table: 1

Table: 2

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

### 4. 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<sub>2</sub> 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<sub>x</sub> from diesel engines. Ammonia is produced on-board by rapid hydrolysis of nonhazardous form of urea solution. In second compartment the NO<sub>x</sub> 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<sub>2</sub> 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 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.

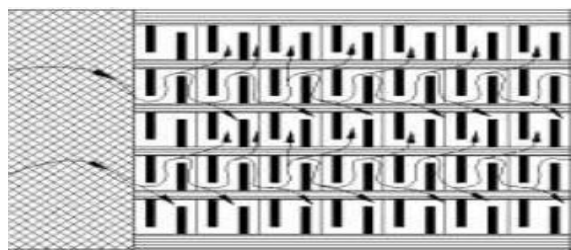


Fig-5: The path of exhaust gas in catalytic converter

## 5. MODELING AND MESHING

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

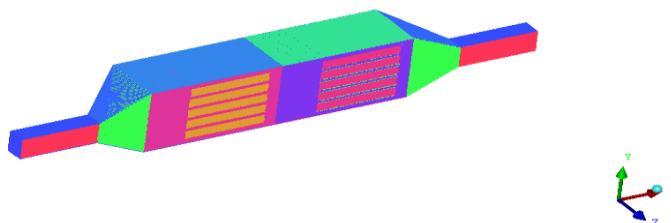


Fig-6: The meshed catalytic converter model

### 5.1 DOMAIN CONDITIONS

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

### 5.2 MATERIAL

Air will be the working fluid considered to be operating at 350 °C and 1.35 bar. The material properties under these conditions are:

Property	Air
Density (kg/m <sup>3</sup> )	0.7534
Viscosity (Pa.s)	3.0927 x 10 <sup>-5</sup>
Specific heat (J/kg-K) (not used)	1056.6434
Thermal conductivity (W/m-K) (not used)	0.0242

## 6. 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 603 cm<sup>3</sup>/s for the assumed vehicle speed of 60 m/s. This gives the necessary inlet speed to the catalytic converter with inlet cross-section of 58 mm x 36 mm as approximately 28.87 cm/s.

Therefore, inlet velocity will be maintained at a slightly higher value of 0.3 m/s and 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.

### 6.1 METHODOLOGY

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

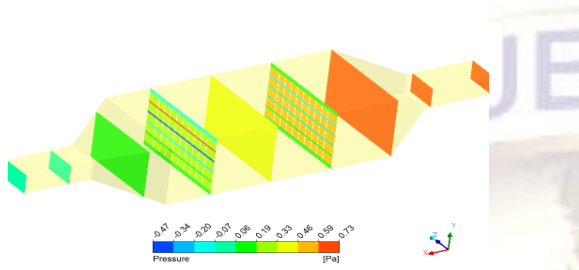
The mesh configuration chosen as MC-1, MC-2 and MC-3 for the catalytic converter model with inlet and outlet conical portion length as:

- 90 mm

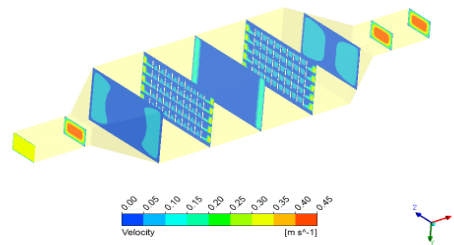
## 7. RESULTS AND DISCUSSION

We have consider the steel wire mesh configuration as MC-1 for all three models of catalytic converter having conical portion length as 70 mm , 80 mm and 90 mm respectively.

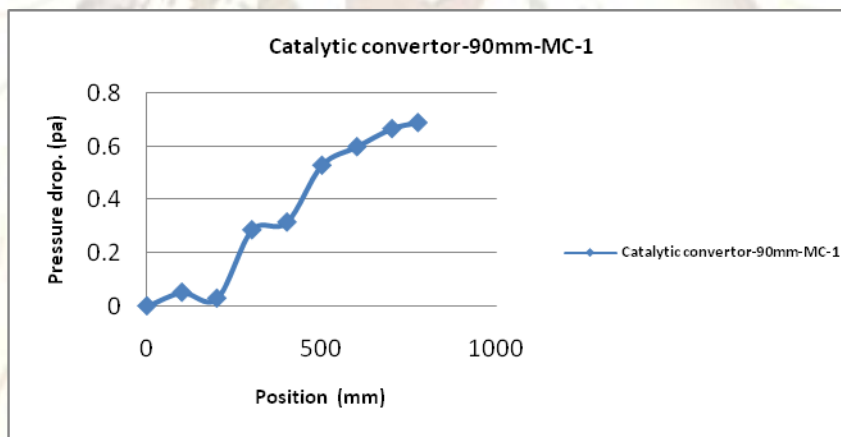
- **CATALYTIC CONVERTER – 90mm – MC – 1**



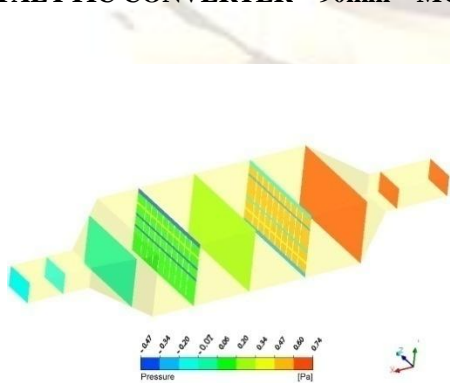
**Fig-11: Pressure contour**



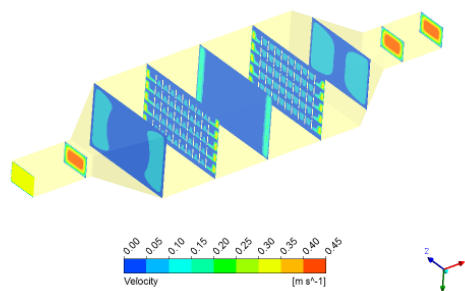
**Fig-12: Velocity contour**



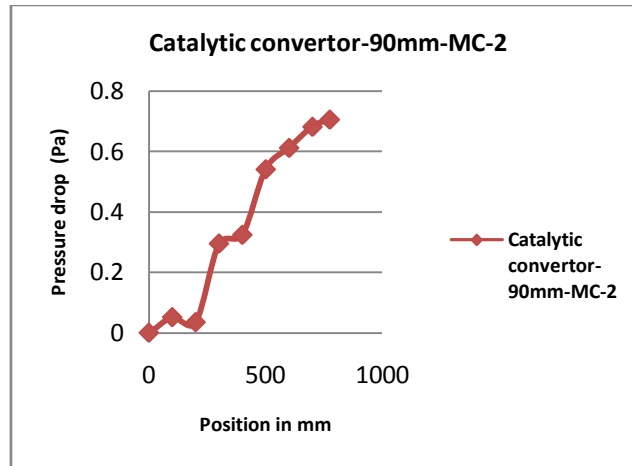
- **CATALYTIC CONVERTER – 90mm – MC – 2**



**Fig-15: Pressure contour**



**Fig-16: Velocity contour**



• CATALYTIC CONVERTER – 90mm – MC – 3

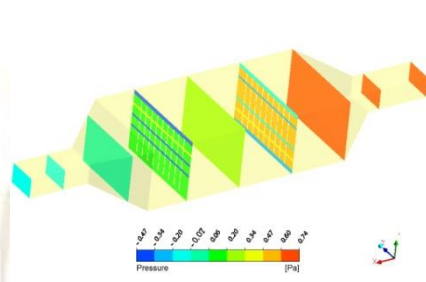


Fig-17: Pressure contour

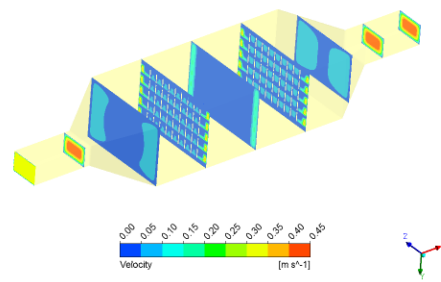
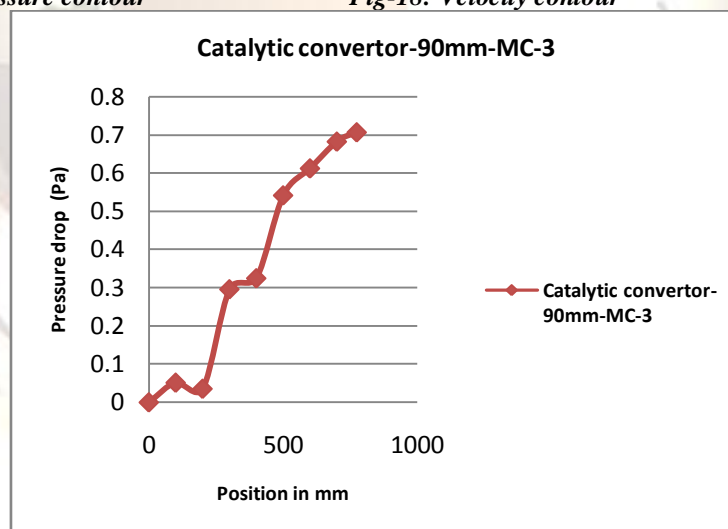


Fig-18: Velocity contour



8. CONCLUSION

It is concluded that the catalytic converter 90mm-MC-1 has the lowest pressure drop among the catalytic converter with different wire mesh grid sizes, due to lower pressure drop the fuel consumption become lower and volumetric efficiency becomes higher. 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.

ABBREVIATIONS

CFD – Computerized Fluid Dynamics  
 NO<sub>x</sub> – Oxides of Nitrogen  
 PM – Particulate Matter  
 DOC – Diesel Oxidation Catalyst

MC – Mesh configuration  
CPSI – Cells per Square Inch

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