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Performance Analysis of Catalytic Converter

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Abstract- The source of pollution and global warming is air pollution. It is to be noted that air pollution is mainly caused by the toxic gases from the exhaust of the automobiles. Only 30 percentage of the fuel is converted into energy source to run the engine remaining 70 percentage of fuel is of un burnt hydrocarbon, carbon monoxide and nitrogen oxides. This toxic content is reduced by the invention of catalytic converter. Here the performance of the catalytic converter is studied and analysis of fluid flow is done. This project deals with the different inlet cone angle of catalytic converter to study the amount of conversion taking place inside the converter after maintaining uniform flow. The uniform flow inside the converter is achieved by increasing the cone angle of the converter. By utilizing the maximum amount of substrate life span of the converter will be increased. It helps to design a better converter model so that it may beneficial for the customer in performance.
Key words – carbon monoxide, Inlet cone Angle, Nitrogen oxides, pressure, Uniform flow.

I. INTRODUCTION

This paper deals with the study of flow inside the catalytic converter; flow inside the converter is non-uniform due to the geometry of the catalytic converter. Analysis of real time catalytic converter is more expensive and if there is any error we have to change the whole model. By using CFD (Computational Fluid Dynamics) Analysis it is easy to spot the errors and rectifying it in an easy way. Catalytic converters are made of substrate at the centre through which the conversion of pollutant will take place [2-4]. When the burnt gases enter into the catalytic converter of certain velocity it will directly hit the substrate at the centre and chemical reactions will take place. The distance between the substrate and the exit of the inlet cone is less so the gas hit the centre portion of the substrate. By this only the centre portion of the substrate is reacted to the inlet gases, so the flow separation at the inlet is not sufficient to expand the flow in all the surfaces of the substrate so that there will be uniform flow inside the converter. Back pressure is the factor which affects the conversion rate of the redox reaction if back pressure increases it leads to failure of the engine.

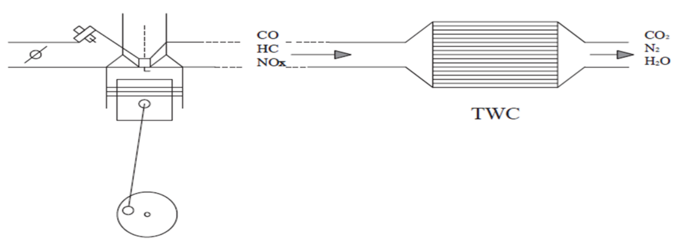

Fig 1 Catalytic converter

A. Catalytic Converter

A catalytic converter is an emissions control device which is used in vehicles that converts toxic pollutants in exhaust gas to less toxic pollutants by catalytic reaction (oxidation or reduction) [1]. Catalytic converters are used in IC engines fuel by either petrol (gasoline) or diesel including lean burn engines. The catalytic converter was invented by Eugene Houdry, a French mechanical engineer in 1950. Houdry concerned about the smoke stack exhaust and automobile exhaust in air pollution and founded a company, Oxy-Catalyst. Houdry first developed catalytic converters for smoke stacks called cats. Then he developed catalytic converters for warehouse forklifts that used low grade non-leaded gasoline.

B. Catalytic Reaction

There are two types of catalytic converter used in automobiles. This is classified on basis of type of catalytic reaction taking

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place in the catalytic converter. They are 2 way catalytic converter and 3 way catalytic converter.

C. Two Way Catalytic Convertor

In two way catalytic convertor, it will control the emission of two different toxic sources. The carbon monoxide and hydrocarbons will be converted into carbon dioxide and water [2].

1) Oxidation of carbon monoxide to carbon dioxide:

$$2CO + O_2 \rightarrow 2CO_2$$

2) Oxidation of hydrocarbons to carbon dioxide and water:

$$4HC + 5O_2 \rightarrow 4CO_2 + 2H_2O$$

The two way catalytic convertor is superseded by three-way converters because of their inability to control oxides of nitrogen.

D. Three Way Catalytic Convertor

The oxides of nitrogen are more toxic than carbon monoxide and hydrocarbons, to control the toxic content of nitrogen oxides effectively with the carbon monoxide and hydrocarbons, three way convertors are designed and used in the automobile industries [2].

1) Reduction of nitrogen oxides to nitrogen and oxygen:

$$2NO_x \rightarrow XO_2 + N_2$$

2) Oxidation of carbon monoxide to carbon dioxide:

$$2CO + O_2 \rightarrow 2CO_2$$

3) Oxidation of hydrocarbons to carbon dioxide and water:

$$2CO + 2NO \rightarrow 2CO_2 + N_2$$

4) Reduction of nitrogen oxides by reactions involving HC and CO:

$$4HC + 10NO \rightarrow 4CO2 + 2H2O + 5N2$$

$$4HC + 5O_2 \rightarrow 4CO_2 + 2H_2O$$

II. PROBLEM DESCRIPTION

A. Non Uniform Flow

The harmful emissions from engines (such as oxides of nitrogen, hydrocarbons, and carbon monoxide) are because of incomplete combustion. Recent catalytic converters are substrate coated with platinum, rhodium, or palladium. Which are Nobel metals and expansive [5-6]. Due to non uniform flow inside the catalytic converter the outer most region of substrate are less reactant to the emission by utilizing these regions we may able to increase the efficiency and life span of the converter. The fig 2.1 shows that due to the non uniform flow the outer most regions are less reactant to the emissions. Pressure at the inlet section increase due to presence of substrate, because of this the flow at the inlet section will reverse in the direction of engine. If this back pressure exceeds then there will be stall in the performance of engine. So reducing back pressure i.e. reverse flow should be less.

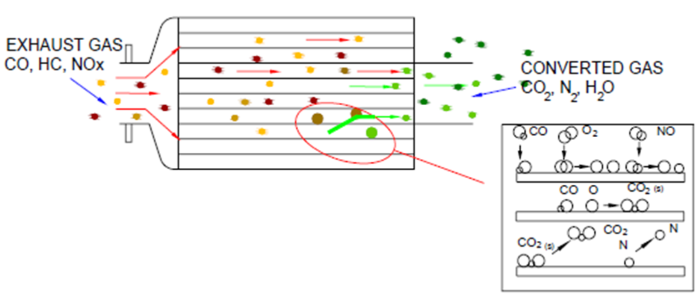


Fig 2 Non uniform flow of Exhaust gases at inlet

B. Reverse Flow

When the fluid flows inside the converter it flows through the inlet section to enter the substrate. The inlet section is an divergence section, the flow passes through the diverging section posses flow separation and as soon the flow comes the end of the divergence section it will start to form vertices near the substrate area which create a reverse flow in the inlet section [3].
Due to the reverse flow the fluid entering into the converter is also affected because of disturbance. This disturbance creates turbulence inside the converter and pressure at the inlet section increases.

III. MODELING THROUGH POROUS MEDIUM

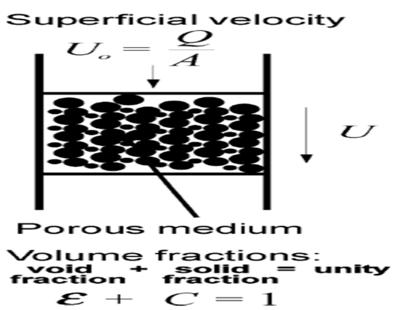
The fluid flows into the converter are designed to be Carbon monoxide. Since the Reynolds number is high, k-ε turbulence model is taken [7]

$$Re= \frac{inertial\ forces}{viscous\ forces} = \frac{\rho VL}{\mu} = \frac{VL}{v}$$

Where V is the mean velocity of the object relative to the fluid, L is a characteristic linear dimension, μ is the dynamic viscosity, *v is the* kinematic viscosity, ρ is the density of the fluid. SIMPLE algorithm is used to get velocity and pressure in the fluid domain by solving the equation of Mass and momentum [7]. The substrate of catalytic converter which is catalyst is taken as porous medium and porosity is given as 1.

A. Consideration of Volume Fraction in Porous Medium

The superficial flow inside the porous bed is defined as total flow rate inside the bed divided by the cross section area.



Where U_0 is superficial velocity, Q is fluid flow rate, A is area of the porous bed, and U is interstitial velocity**.** To preserve fluid continuity with the entering superficial flow the fluid will have to pass through a smaller area; hence the velocity within the bed will be greater than the superficial. In particle technology calculations it is the volume fraction is most important than the mass fraction

B. Governing Equation

Governing equations solved by the software for this study in tensor Cartesian form are Continuity and Momentum equations.

Continuity equation:

$$\rho\left(\frac{\partial u_j}{\partial x_j}\right)=0$$

Momentum equation:

Momentum x:

$$\rho\frac{\partial u}{\partial t} = \rho g_x - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

Momentum y:

$$\rho\frac{\partial v}{\partial t} = \rho g_y - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right)$$

Momentum z:

$$\rho\frac{\partial w}{\partial t} = \rho g_z - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right)$$

Where,

ρ = density, g = gravitational force

IV. METHODOLOGY

In this paper CFD study for five different geometry of catalytic converter is studied. The inlet geometry of the converter is changed with respect to right angle triangle theorem. From the converter the portion of substrate to the inlet angle is said to be in form of right angled triangle.

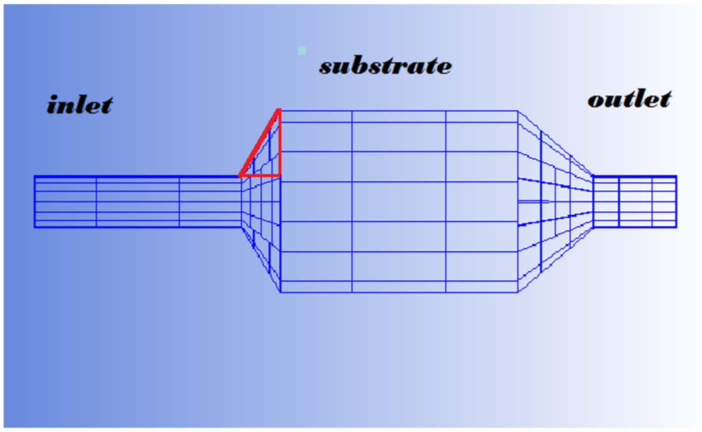


Fig 3 Inlet Geometry of Converter

A. Inlet Geometry

The inlet geometry of the converter is calculated from the known values of height and required angle.

Table I
Inlet Geometry

ANGLE (degree)	DISTANCE BETWEEN SUBSTRATE AND DIVERGENCE SECTION (mm)
90	50 (OFFSET)
60	47.5
50	70
30	142
15	300
10	466
5	940

The above table contains the calculated inlet geometry for new converter with respect to various divergence angles at inlet. By analysis we can able to predict the pressure at inlet for all the above converters. The performance of the converter is high when the pressure at inlet is less. Flow uniformity index at the porous section is also predicted from the analysis to justify there is less flow separation at the inlet section.

B. Boundary Condition

For incompressible flow through a channel, any perturbation of the flow at one point is instantly felt everywhere in the fluid. The state of flow is everywhere consistent. In such case Inlet and outlet boundary can be set as velocity and pressure respectively.

Table II
Boundary Condition

Inlet	velocity
Outlet	pressure
Porosity	1
Fluid	Carbon Monoxide
Velocity	$25ms^{-1}$
Pressure	1 atm

V. RESULTS AND DISCUSSIONS

The fluid flow inside the catalytic converter is discussed here; the non uniform flow inside the converter is due to the flow separation at the inlet divergence section. The Pressure at inlet increases because of the substrate, which is placed at the path of flow. The following contour of total pressure and mass flow rate plot will explain the efficiency of catalytic converter after changing the inlet geometry.

A. Total Pressure

Model I

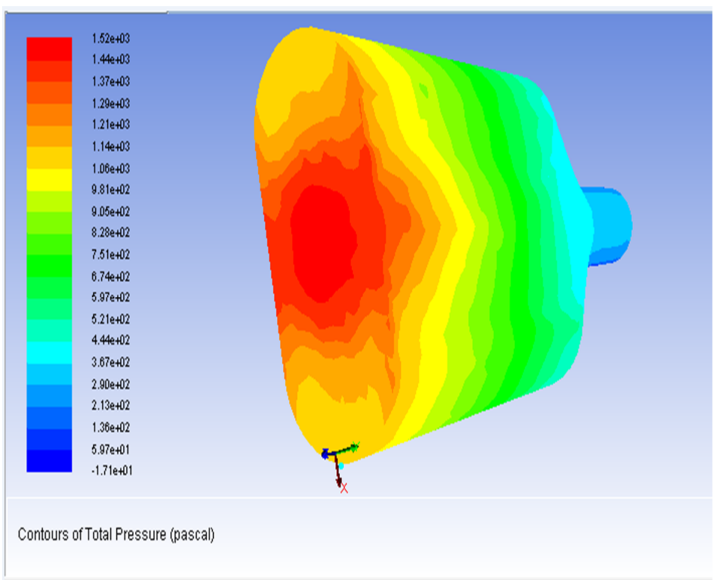


Fig 3 Total Pressure Contour of Inlet Angle 90^0

Model II

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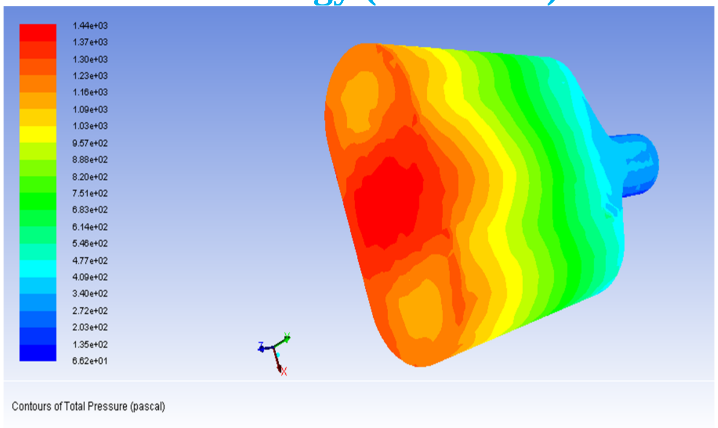

Fig 4 Total Pressure Contour of Inlet Angle 60^0

Model III

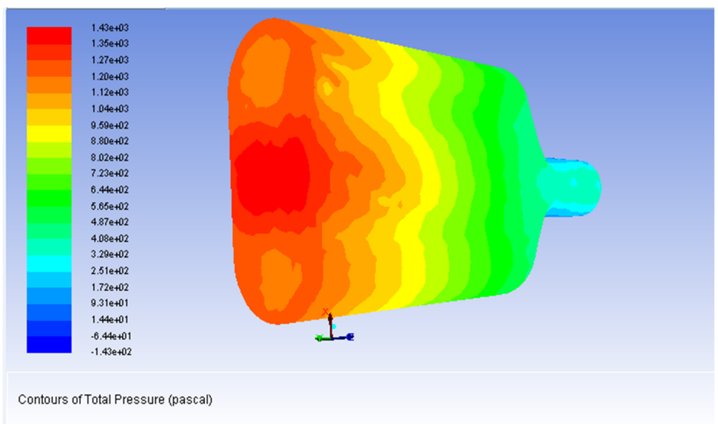

Fig 5 Total Pressure Contour of Inlet Angle 50^0

Model IV

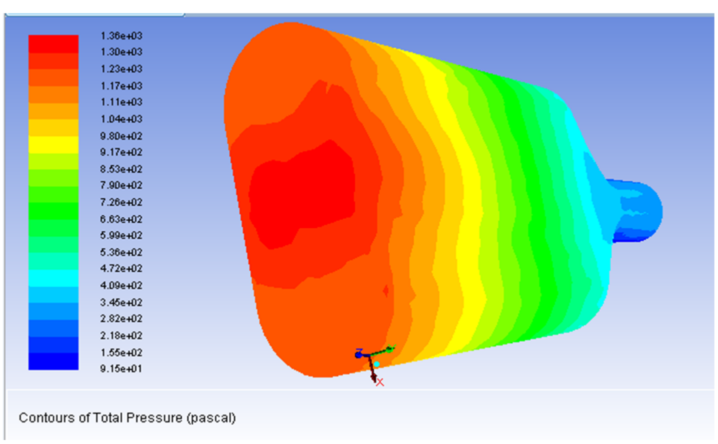

Fig 6 Total Pressure Contour of Inlet Angle 30^0

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Model V

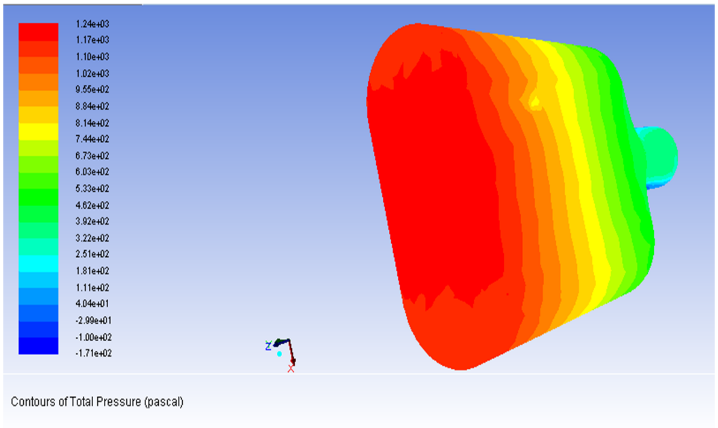

Fig 7 Total Pressure Contour of Inlet Angle 15^0

Models of 10^0 and 5^0 are not taken for analysis because of space constrain. It is not possible to design a converter with huge inlet dimension. The pressure at inlet of all the Models is tabulated for study.

Table III
Pressure at Inlet

Angle	Pressure (Pa)
90	1520
60	1440
50	1430
30	1360
15	1240

The above tabulation showed that the pressure for each inlet angle of converter.

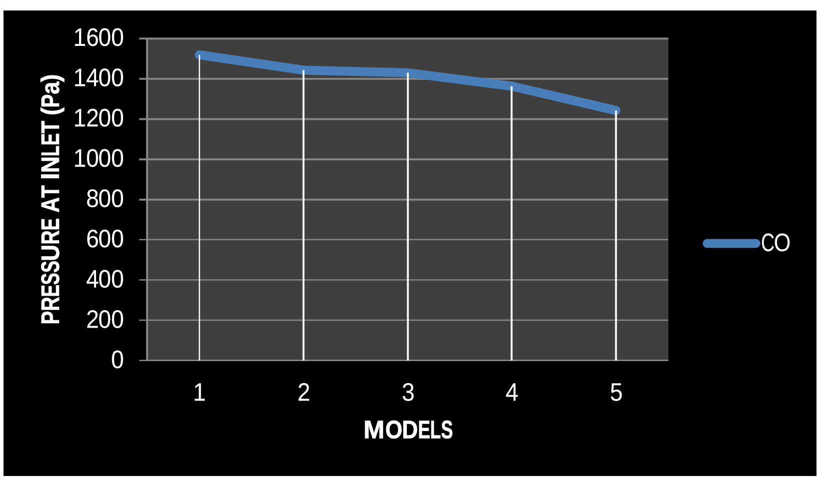

Fig 8 Angle and Pressure Chart

The total pressure and angle of the converter shows that pressure at inlet is directly proportional to divergence angle. When inlet angle decreases, then the pressure at inlet decrease. Flow separation is less at low divergence angle is justified.

B. Flow Uniformity Index

Uniformity index is the normalized RMS of the difference between the local velocity and the spatial mean of the velocity integrated over the area of cross section

$$\gamma = 1 - \int_A^0 \frac{\sqrt{(U' - U)^2}}{2AU'}$$

Where, γ is the Uniformity index, A is Area of cross section U' is Average Velocity and U local velocity. Uniform flow inside the converter may help in improving the performance, lack of uniformity is due to the flow separation at divergence section. Flow uniformity increases the amount of substrate utilized by the toxic fluids with is the sign of good converter. Here flow uniformity index at the porous section is plotted below.

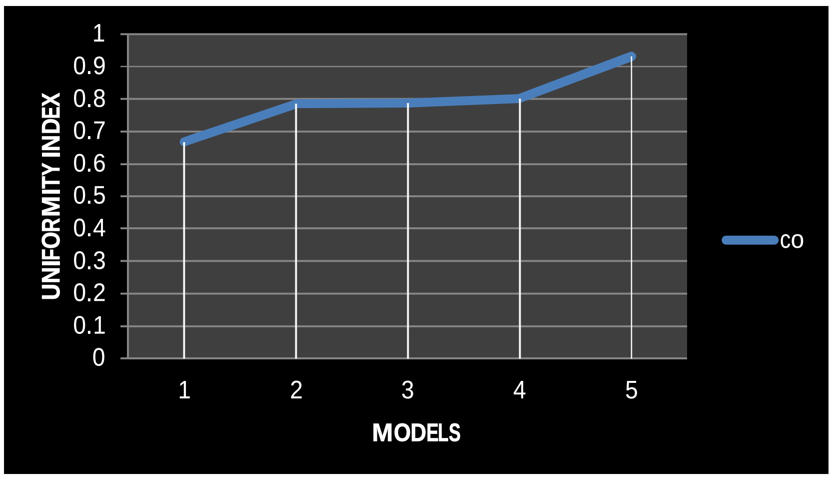

Fig 9 Uniformity index

VI. CONCLUSION

In this paper it is clearly stated the performance of the catalytic converter can be increased by decreasing the divergence angle [1]. The pressure at inlet increases with respect to inlet divergence angle. By decreasing the inlet divergence angle of the catalytic converter we may able to increase the flow uniformity is shown in the graph. Pressure at inlet is directly proportional to inlet angle. Analysis is done in FLUENT package and substrate is considered as porous medium with proper resistance.

The flow inside the converter is non uniform due to the vortices formed at the inlet section and pressure reduction is achieved by this modification is shown clearly in result and discussion topic. The results of the analysis show that the lower pressure can be achieved by changing the inlet angel to $15^0$for better performance.

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