DESIGN, ANALYSIS OF FLOWCHARACTERISTICS OF CATALYTIC CONVERTERANDEFFECTS OF BACKPRESSURE ON ENGINE PERFORMANCE

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ABSTRACT

Now a days the global warming and air pollution are big issue in the world. The more amount of air pollution is due to emissions from an internal combustion engine. Catalytic converter plays a vital role in reducing harmful gases, but the presence of catalytic converter increases the exhaust back pressure.

This paper deals with the catalytic converter designed and through CFD (Star CCM+ software) analysis, a compromise between two parameters namely, more filtration efficiency with limited back pressure was aimed at. In CFD analysis, various models with different wire mesh grid size combinations were simulated using the appropriate boundary conditions and fluid properties specified to the system with suitable assumptions. The back pressure variations in various models and the flow of the gas in the substrate were discussed in. Finally, the model with limited backpressure was fabricated and Experiments were carried out on computerized kirloskar single cylinder four stroke diesel engine test rig with an eddy current dynamometer. The performance of the engine and the catalytic converter were discussed.

Keywords: Engine emissions, Catalytic converter, CFD, Backpressure, Fuel Consumption

I. INTRODUCTION

Catalytic converter is vehicle emission control device which converts toxic by-products of combustion in the exhaust of an internal combustion engine to less toxic substances by way of catalysed chemical reactions.

During the exhaust stroke when the piston moves from BDC to TDC, pressure rises and gases are pushed into exhaust pipe. Thus the power required to drive exhaust gases is called exhaust stroke loss and increase in speed increases the exhaust stroke loss.

The net work output per cycle from the engine is dependent on the pumping work consumed, which is directly proportional to the backpressure. To minimise the pumping work, backpressure must be low as possible. The backpressure is directly proportional to the catalytic converter design. The catalytic substrate and shape of the inlet cone contribute the backpressure. This increase in backpressure causes increase in fuel consumption.

Indeed, an increased pressure drop is a very important challenge to overcome. Typically, an engine will lose about 300 W of power per 1000 Pa of pressure loss. As a result, a trade-off between the pressure loss and total surface area has become the main concern in determining the appropriate geometry of catalytic converters.

The pressure drop in catalytic converters is associated with two major components: substrate and flow distribution devices (manifold, inlet and outlet pipe, as well as inlet and outlet diffuser) . The substrate makes the largestcontribution of the exhaust backpressure.

II. DESIGN CALCULATION

Shape of Catalytic Converter

The cylindrical shape was considered due to ease of fabrication, minimum assembly time, rigidity and easier maintenance.

Volume of Catalysts

Space Velocity: The space time necessary to process one reactor volume of fluid.

It is also called as holding time or residence time.

Assuming (for single cylinder engine) = 20000 hr^{-1}

$$\text{Space Velocity} = \frac{\text{Volume flow rate}}{\text{Catalysts Volume}}$$

$$\text{Volume flow rate} = \text{Swept volume x Number of Intake Stroke per hr}$$

$$= \frac{\pi}{4} * (0.0875)^2 * (0.110) * \frac{1500}{2} * 60 = 29.31\text{m}^3$$

$$\text{Catalysts Volume} = \frac{\text{Volume flow rate}}{\text{Space Velocity}}$$

$$= \frac{29.31}{20000} = 0.001465\ m^3 \quad = 1465 \text{ ml}$$

Shell Dimension

- The Shell is the central cylindrical part between the inlet and outlet cones.
- This part contains circular discs with coated pellets.

$$V_{catalyst} = \frac{\pi}{4} * D^2 * L \quad mm^3$$

Where, D – Diameter of the catalyst

L – Length of the catalyst (assume L=2D)

$$0.001465 = \frac{\pi}{4} * 2 * D^3$$

$$D = 0.0977 \text{ m} \ = 97.7 \text{ mm} \cong 100 \text{ mm}$$

L = 2*100 = 200 mm

Length of the shell = 200 mm

III. WIREMESH GEOMETRY

The square-shaped with 400 cells per square inch and a thickness of 4.5 mil (0.114 mm) honey comb monolith was employed in the current study.

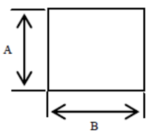


TABLE I. GEOMETRY

PARAMETERS	
A(mm)	1.27
B(mm)	1.27
Cell Length (mm)	200
Cell Density (cpsi)	400

IV. MATHEMATICAL MODELLING

Air is used as fluid media, which is assumed to be steady and compressible. High Reynolds number k-ε turbulence model is used in the CFD model. This turbulence model is widely used in industrial applications. The equations of mass and momentum are solved using SIMPLE algorithm to get velocity and pressure in the fluid domain. The assumption of an isotropic turbulence field used in this turbulence model is valid for the current application. The near-wall cell thickness is calculated to satisfy the logarithmic law of the wall boundary. Other fluid properties are taken as constants. Filter media of catalytic converter is modelled as porous media using coefficients. For porous media, it is assumed that, within the volume containing the distributed resistance there exists a local balance everywhere between pressure and resistance forces such that

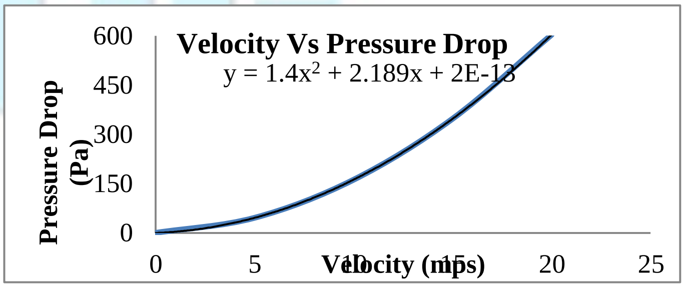
$$-K_i u_i = \frac{\partial p}{\partial \xi_i}$$

Where ξi(i= 1, 2, 3) represents the (mutually orthogonal) orthotropic directions. K_i is the permeability,u_i is the superficial velocity in direction ξiThe permeability. K_i is assumed to be a quasi linear function of the superficialvelocity. Superficial velocity at any cross section throughthe porous medium is defined as the volume flow ratedivided by the total cross sectional area (i.e. area occupiedby both fluid and solid).

To find the viscous resistance and inertial resistance the pressure drop test was conducted along the one meter length of the wire mesh substrate with different velocities. Velocity, v/s Pressure drop, Δpplotted in the graphical representation. From the plot we can find the polynomial function for the pressure drop.

TABLE II: EXPERIMENTAL DATA

Velocity (m/s)	Pressure Drop (Pa)
0	0
5	45.9
10	161.89
15	347.84
20	60.378



The polynomial equation for unit length,

$$\Delta p = 1.40v^2 + 2.189v$$

For simple homogeneous media,

$$\frac{\Delta p}{L} = -C_2 * \frac{1}{2} * \rho * v_i^2 - \frac{\mu}{\alpha} v_i$$

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Where, $\frac{1}{\alpha}$is viscous resistance & C_2 is inertial resistance factor.

V. THREE DIMENSIONAL CFD STUDY

A three-dimensional model of a catalytic converter is generated in CFD tool Star CCM+ 7.02 for the analysis.

1) ModelingAnd Meshing

The geometry of the element is made as tetrahedral mesh, with a refined mesh near the wall. The K-E turbulence model is used, with standard wall functions for near-wall treatment.

2) Governing Equations

CFD solver Star CCM+ is used for this study. It is a finite volume approach based solver which is widely used. Governing equations solved by the software for this study in tensor Cartesian form are

Continuity: $\rho\left[\frac{\partial u_j}{\partial x_j}\right] = 0$

Momentum:

$$\rho\frac{\partial}{\partial x_j}(u_j u_i) = -\frac{\partial p}{\partial x_j} + \frac{\partial \tau_{ij}}{\partial x_j} + S_{cor} + S_{cfg}$$

VI. METHODOLOGY

The table shows that the parameters of the models.

TABLE: PARAMETERS OF MODELS

Model No.	Diameter of the catalyst brick (mm)	Length of the catalyst (mm)	Inlet Cone Angle(deg)
1	100	200	80
2	100	200	54
3	100	200	40
4	150	130	120
5	150	130	90
6	150	130	70

In CFD analysis two major flow characteristics (back pressure and vorticity) were studied.

Study 1: In study I, the vorticity of the structures were studied. This study offered to find the recirculation zones which cause the in-active zones in the DOC. The models which produce the lesser vorticity were selected for further studies.

Study II: In study II, the models which had the lesser vorticity were studied for the flow pattern. The back-pressure characteristics of the models were modelled and the model having the lesser backpressure was taken for experimental study.

VII. CFD RESULTS & DISCUSSION

The primary aim of this CFD analysis is to find out the right shape of catalytic converter for the exhaust manifold which can offer minimum back pressure.

a) Vorticity in models

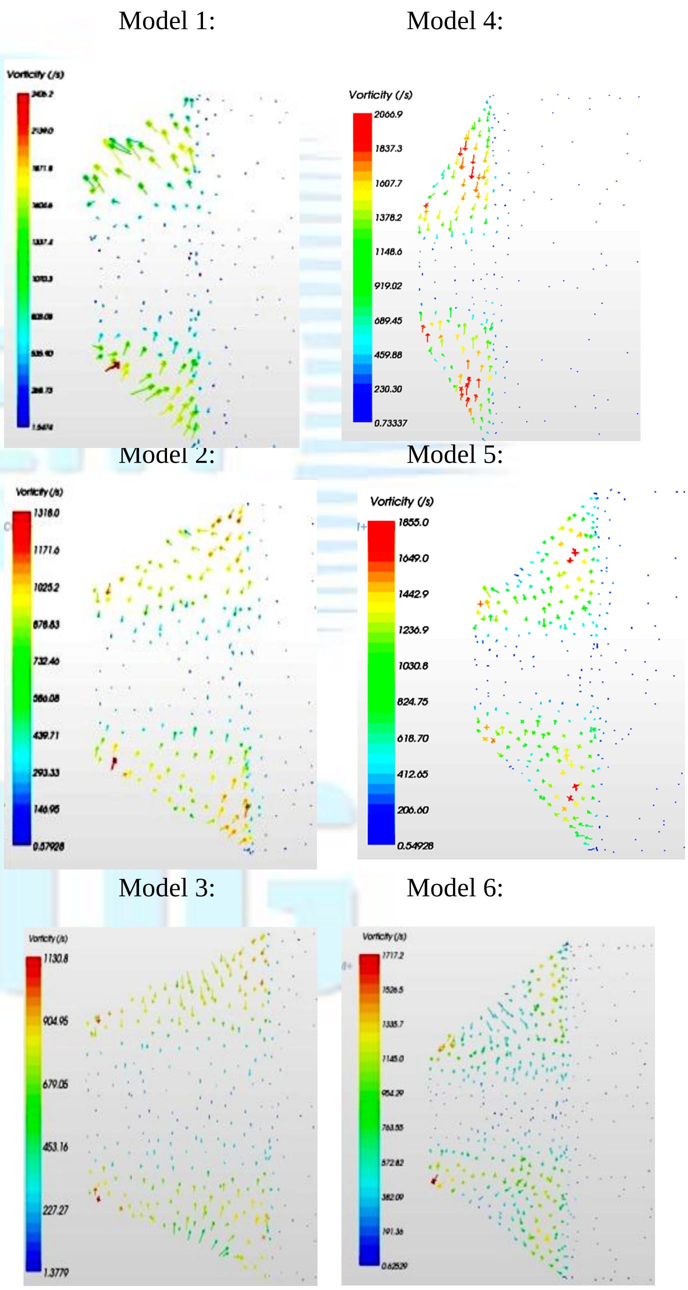

FIGURE 1: VORTICITY OF THE MODELS

It is observed that the vorticities in the models 4, 5 &6 are found to be higher than the models 1, 2 & 3. The higher in the

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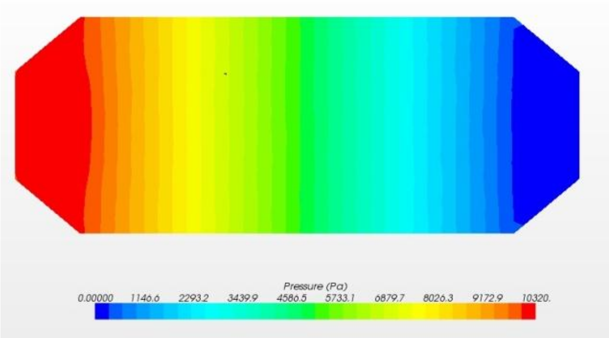
vorticity results the higher recirculation zones. The increase in recirculation causes the more in-active zones in DOC. This is termed as non-uniformity. The non-uniformity reduces the conversion of the harm gases. Also reduces the utilization of the noble materials. The noble materials like rhodium, platinum are more costlier.

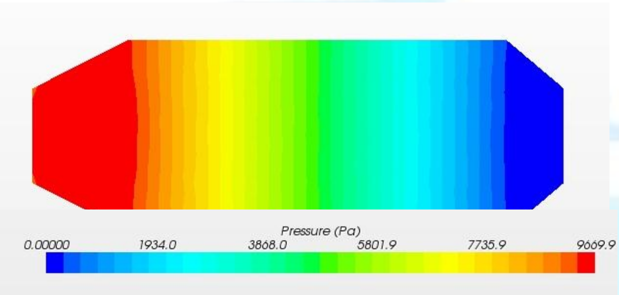
b) Back Pressures in Models:

It is observed that the back pressure in model 1, 2 and 3 are found to be 10.3kPa, 9.6 kPa and 9.0 kPa respectively asshown in Figure 2. The back pressure is found to bereduced with the increase in length of taper for the same inlet conditions.

Model 1:



Model 2:



Model 3:

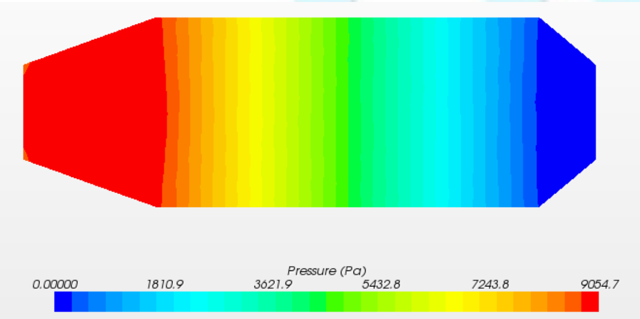
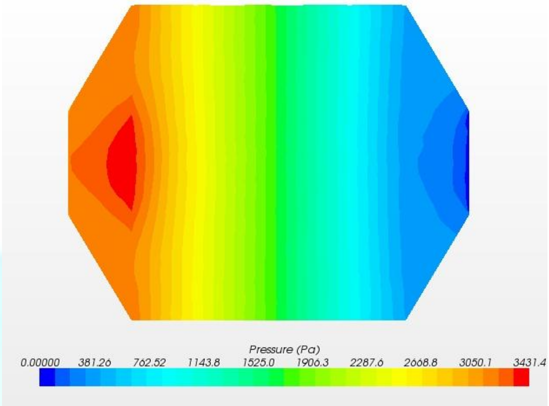


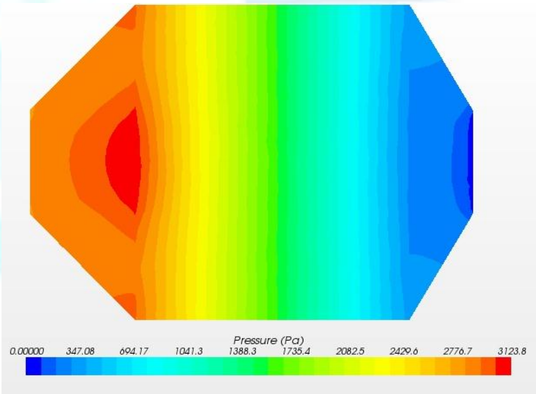
FIGURE 2: BACKPRESSURE ANALYSIS

Similarly the back pressure analyses were carried out for other three models 4, 5 & 6. For these models the back pressure was lesser than the models 1, 2 & 3.

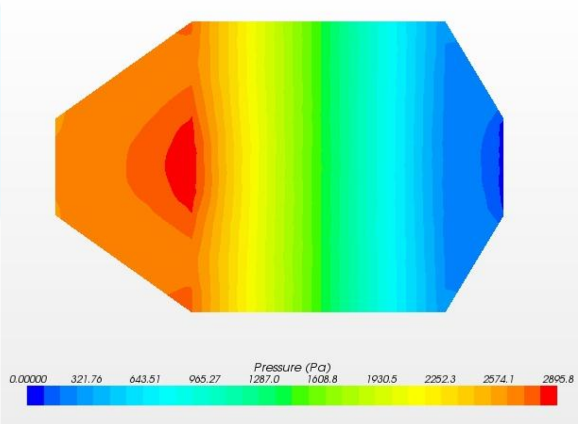
Model 4:



Model 5:



Model 6:



VIII. EXPERIMENTAL RESULT& DISCUSSION

The experimentation was conducted with the 150mm diameter catalytic converter in single cylinder four stroke diesel engine. The catalytic converter was fitted on the engine exhaust at the distance of 300 mm from the exhaust flange. Then the performance study was conducted and plotted against the brake power.

FIGURE 4: ENGINE SETUP WITH CATALYTIC CONVERTER

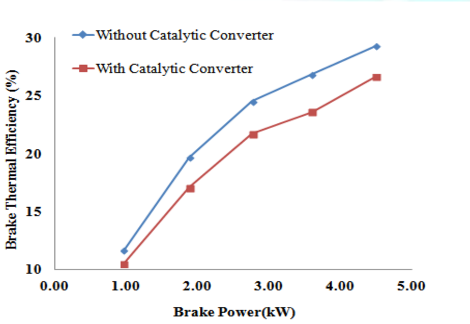


FIGURE 5: BRAKE POWER vs BRAKE THERMAL EFFICIENCY

The figure 5 shows that the variations in the brake thermal efficiency. Considerable reduction in brake thermal efficiency is observed while using the catalytic converter. There is 10 to 15% of brake thermal efficiency increased.

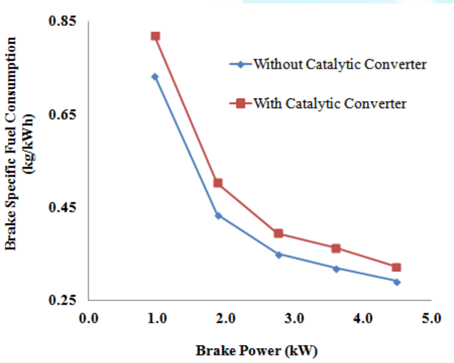


FIGURE 6: BRAKE POWER vs BRAKE SPECIFIC FUEL CONSUMPTION

The figure 6 shows that the variations in the brake specific fuel consumption. It is observed that there is a considerable increase in brake specific fuel consumption while using the catalytic converter. From the graph, approximately 15% of bsfc observed that is in increasing trend

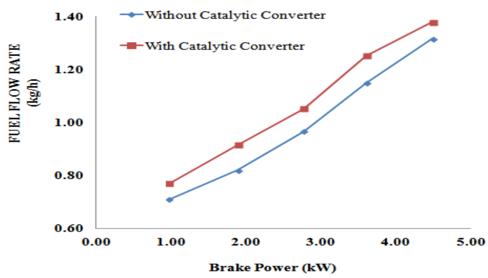


FIGURE 7: BRAKE POWER vs FUEL FLOW RATE

The figure 7 shows that the variations in the fuel consumption. It is observed that there is a considerable increase in fuel flow rate with increase in brake specific fuel consumption while using the catalytic converter. From the graph, approximately 15% increase of fuel flow rate as bsfc.

IX. CONCLUSIONS

The following conclusions may be drawn from the present study.

The catalytic converter was successfully designed.

Through CFD analysis, the vorticity and backpressure of various catalytic converter models were studied.

The increase in inlet cone angle increases the vorticity of the flow which leads to in-active zones.

The increase in inlet cone length reduces the backpressure and also reduces the recirculation zones.

Installation of the catalytic converter reduces the brake thermal efficiency and increases the brake specific fuel consumption, fuel flow rate.

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