PERFORMANCE AND CFD ANALYSIS OF CATALYTIC CONVERTER IN IC ENGINES

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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 CFD (Star CCM+ software) analysis of catalytic converter, a compromise between two parameters namely, more filtration efficiency and limited back pressure was aimed at. In CFD analysis, various models with wire mesh grid size 400 cells per square inch 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, Hexagonal type

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 minimize 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.

II LITERATURE SURVEY

Thundil Karuppa Raj R. and Et al (2012) were studied the numerical study of fluid flow and effect of inlet pipe angle in catalytic converter using CFD. The numerical results were used to determine the optimum geometry required to have a uniform velocity profile at the inlet to the substrate. PL.S. Muthaiah and Et al were analysed the catalytic converter to reduce particulate matter and achieve limited back pressure in diesel engine using CFD tool. The back pressure variations in various models are discussed in this paper. V.K. Pravin and Et al 2012 were investigated the numerical investigation of various models of catalytic converters in diesel engine to reduce particulate matter and achieve limited back pressure. Through CFD analysis, various models with different wire mesh grid size combinations were simulated using the appropriate boundary conditions.. M A Kalam and Et al (June 2009) were developed a low-cost three way catalytic converter to use with CNG-DI engine. The catalytic converter were developed based on catalyst materials consisting of metal oxides such as titanium dioxide (TiO2) and cobalt oxide with wire mesh substrate. Douglas Ball and Et al (2007) were performed with a 1.3L catalytic converter design containing a front and rear catalyst each having a volume of 0.65 liters. This investigation varied the front catalyst parameters to study the effects of 1) substrate diameter, 2) substrate cell density, 3) Pd loading and 4) Rh loading on the FTP emissions on three different vehicles. Jonathan D. Pesansky and Et al (2009) were studied an estimate of the potential effect of substrate and exhaust system backpressure on engine performance. Parameters include fuel consumption, CO_2 emissions, and horsepower. Finally, the potential impact of exhaust system backpressure on real world driving conditions is discussed. P. V. Walke and Et al (2008) were designed and developed the catalytic converter with different catalysts copper oxide (CuO), cerium oxide (CrO_2) and zirconium dioxide (ZrO_2). Experiments were carried out on computerized kirloskar single cylinder four stroke (10 B.H.P, 7.4 kW) diesel engine test rig with an eddy current dynamometer. The converter was tested with different catalyst. In this project, we have been noticed that we have selected the shape and geometry of the catalytic converter which is Octagonal type. Moreover materials were selected according to the prescribed norms. And we have designed the Octagonal shape catalytic converter, once we got the appropriate datas. Among the Three models that we have fabricated for inlet cone length 70mm. Through CFD Analysis, various models like (inlet cone length 30mmm and 50 mm) with different wire mesh grid size combinations were simulated using the appropriate boundary conditions. The Geometrical dimensions which we have taken through CFD Analysis that we have fabricated. The back pressure is created due to the installation of Octagonal type catalytic converter that is measured for the different speed and load conditions and the engine performance were carried out. The effect of the back pressure was studied. Then the discussion on the results were carried out and tabulated. The comparison of back pressure of different catalytic converter was made that is compared with Octagonal type catalytic converter.

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.

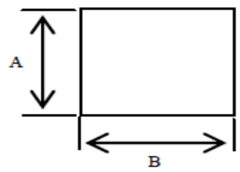


TABLE I. GEOMETRY

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

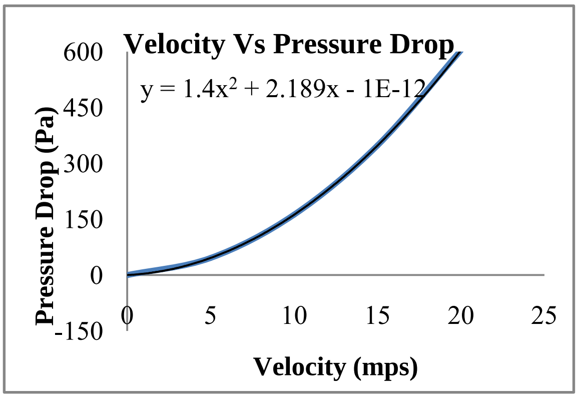
III. MATHEMATICAL MODELLING

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 superficial velocity. Superficial velocity at any cross section through the porous medium is defined as the volume flow rate divided by the total cross sectional area (i.e. area occupied by 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, Δp plotted 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,

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

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

IV. 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) Modeling And 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:

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

V. METHODOLOGY

The table shows that the parameters of the models having hexagonal cross section.

TABLE III: PARAMETERS OF MODELS

Model No.	Hexagonal Side	Length of the catalyst (mm)	Inlet Cone Angle(deg)
1	40	200	80
2	40	200	54
3	40	200	40

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

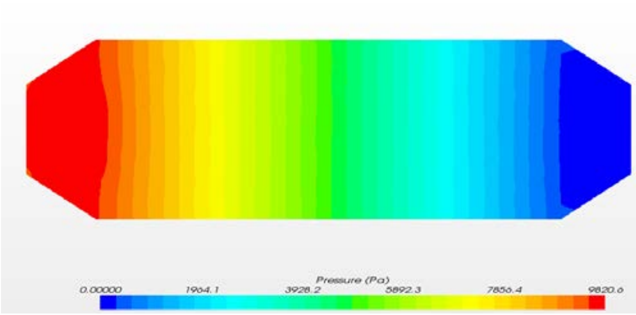
VI. CFD RESULTS & DISCUSSION

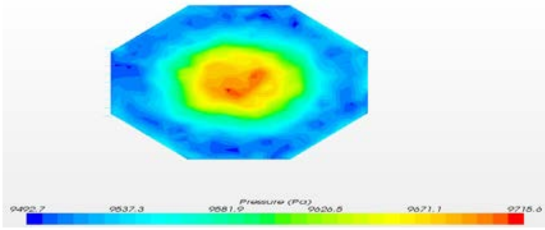
The primary aim of this CFD analysis is to find out the right shape of catalytic converter for the exhaust manifold which can offer minimum back pressure.

Back Pressures in Models:

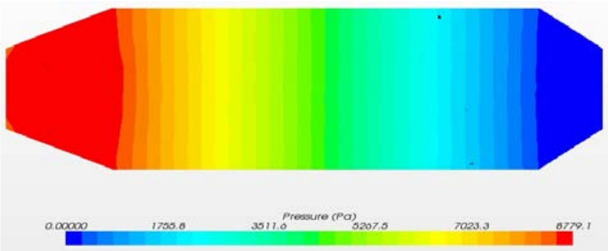
It is observed that the back pressure in model 1, 2 and 3 are found to be 10.3 kPa, 9.6 kPa and 9.0 kPa respectively as shown in Figure 2. The back pressure is found to be reduced with the increase in length of taper for the same inlet conditions

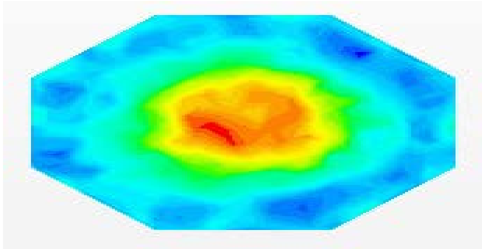
MODEL 1:



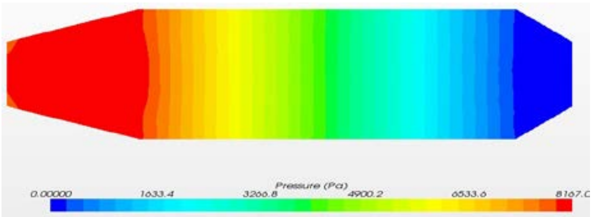


MODEL 2:





MODEL 3:



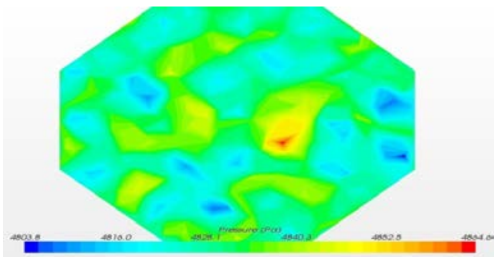


FIG 1: BACKPRESSURE ANALYSIS

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.

VII. EXPERIMENTAL RESULT & DISCUSSIONS

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.

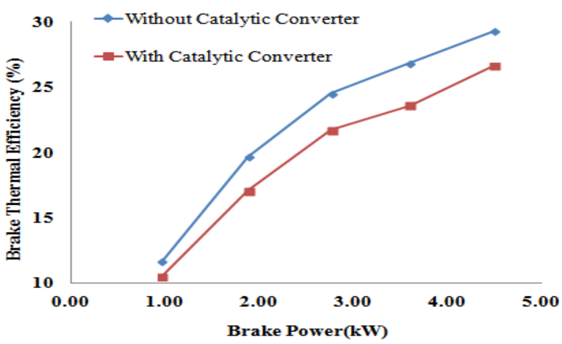


FIG 2: BRAKE POWER vs BRAKE THERMAL EFFICIENCY

The figure 2 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.

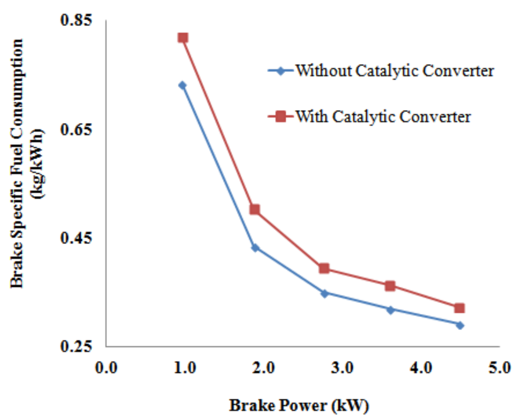


FIG 3: BRAKE POWER vs BRAKE SPECIFIC FUEL CONSUMPTION

The figure 3 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

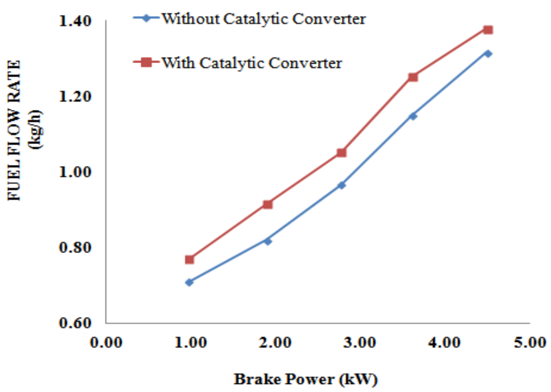


FIG 4: BRAKE POWER vs FUEL FLOW RATE

The figure 4 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.

EMISSION CHARACTERISTICS

The emissions CO, HC and smoke were measured and comparison was made for the conversion of harmful gases with the catalytic converters.

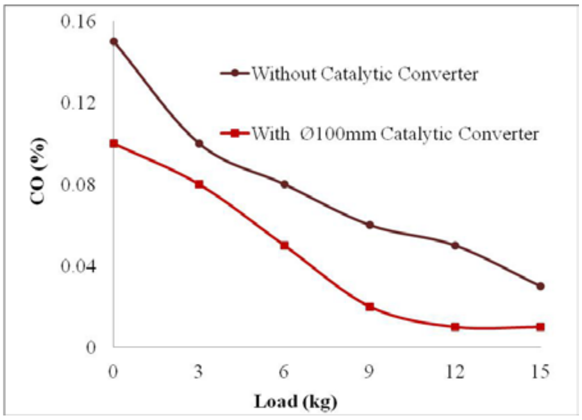


Fig.5: Load (vs.) Carbon Monoxide

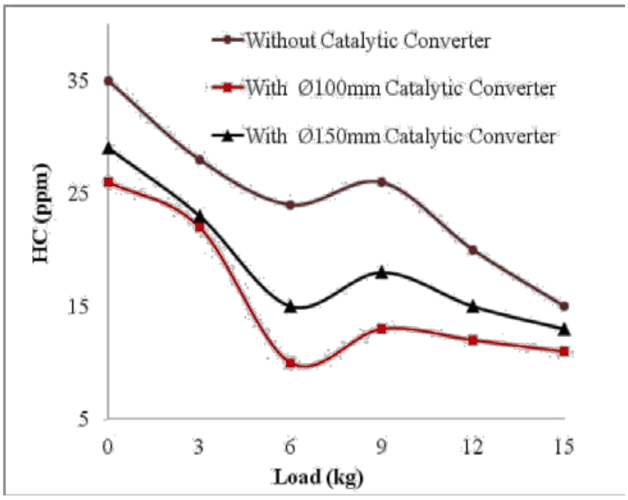


Fig 6: Load (vs.) Unburned Hydrocarbons

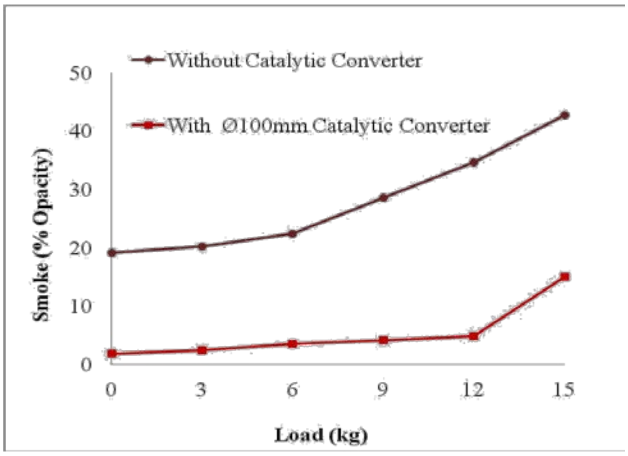


Fig 7: Load (vs.) Smoke

Fig 6 has explained that the unburned hydrocarbons levels were checked with respect to load. More over we resulted that unburned hydrocarbons levels were considerably low while compared to without catalytic converter.

Fig 7 has explained that the levels of smoke were checked against different load conditions More over we have resulted that the levels of smoke were considerably low while compared to without catalytic converter.

VIII CONCLUSIONS

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