Design and Analysis of Catalytic Converter of Automobile Engine.

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Abstract - *A major part of the air pollution caused is due to the vehicular emission which is increasing at an alarming rate. The different types of vehicles like car, bus, truck etc. contribute a way as well as play a dominant duty in increasing air pollution. These vehicles find its running source mainly from the extracts of fossil fuels like petrol, diesel. The fuels undergo combustion to generate energy so as to support the vehicle for duty. The incomplete combustion of the fuels in the engine paves a way for production of products like the carbon monoxide, hydrocarbons and particulate matters. A high emission level is therefore a proved result.*

For the purpose of forcing the fuel to have efficient combustion and for reduction of the emission levels for reducing air pollution a wide range of processes are applicable. These include improvising engine design, fuel pre-treatment etc. Among these wide ranges of options available catalytic converter is found to be a better way for establishing an efficient combustion in the controller engine of the vehicle. Usage of noble group metal is an effective way for effective combustion like the platinum group metal serves way good for reducing the exhausts. With the help of secondary measures efficiency of the engine is improved as well. The techniques are still under development as because there are some limitations of the catalytic converters which are needed to be dealt with but the application of this technique has better achievement points as well.

Key Words: CFD, Catalytic Converter, Particulate Matter (PM), Wire Mesh.

1. INTRODUCTION

The simplest and the most effective way to reduce NOx 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 presence of catalytic converter increase back pressure in engine.

In Internal combustion Engines loose a small amount of work due to exhausting of burnt gases from the cylinder and the admission of fresh charge into the cylinder. This loss of power due to gas exchange process is due to pumping gas from lower inlet pressure to higher exhaust pressure. The gas exchange processes affects the volumetric efficiency of the engine. The performance of the engine, to a great deal, depends on the volumetric efficiency. During the exhaust stroke when the piston moves from bottom dead centre to top dead centre, pressure rises and gases are pushed into exhaust pipe. Thus the power required to drive the exhaust gases is called the exhaust stroke loss and increase in speed increases the exhaust stroke loss.

Therefore it is clear from the above discussion that 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, the backpressure must be as low as possible for obtaining the maximum output from the engine. The backpressure is directly proportional to the pressure drop across the catalytic converter or design of complete exhaust system components causing the back pressure. Therefore exhaust system components and devices such as catalytic converter, in this case must be designed for minimum backpressure so that it should not disturb the engine as well as other subsystems operation. The present work therefore is an attempt to reduce exhaust emissions using copper as a catalyst without affecting engine performance.

1.1 OBJECTIVE OF PRESENT WORK

i. To understand the concept of conventional catalytic converter very well and depending on that overcomes the various negative aspects.
ii. To improve the performance of conventional catalytic converter by changing its design criteria.
iii. To minimize the backpressure effect on engine by changing and testing the honeycomb structure of catalyst.
iv. To determine Pressure and velocity analysis of catalytic converter of an Automobile Engine.
v. To examine various design parameter of catalyst of automobile catalytic converter.
vi. To evaluate the effect of CO exhaust gas mass fraction via catalyst.

vii. To develop modified design of automobile catalytic converter.

2. PROCESS

2.1 CAD: Initially design of Catalytic converter is completed in CATIA and reference of conventional Catalytic converter is taken so that effect of changes in various design parameters of Catalytic converter can be checked. The basic design of Catalytic converter is considered for simulation on which various design modification cases can be solved and effect of design parameter can be checked. CAD of Catalytic converter and Major Dimensions of Catalytic converter are given below-

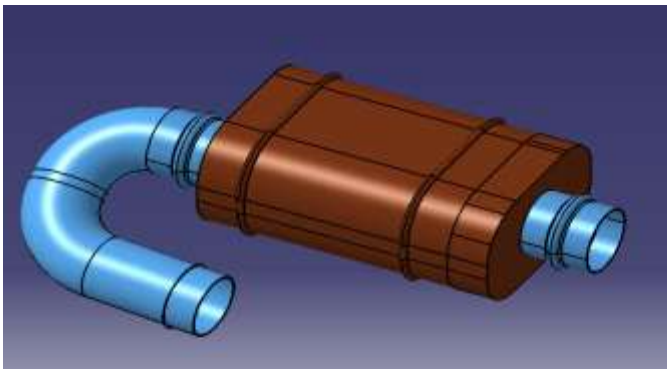

Fig -1: Base Catalytic Converter

2.2 Dimensions

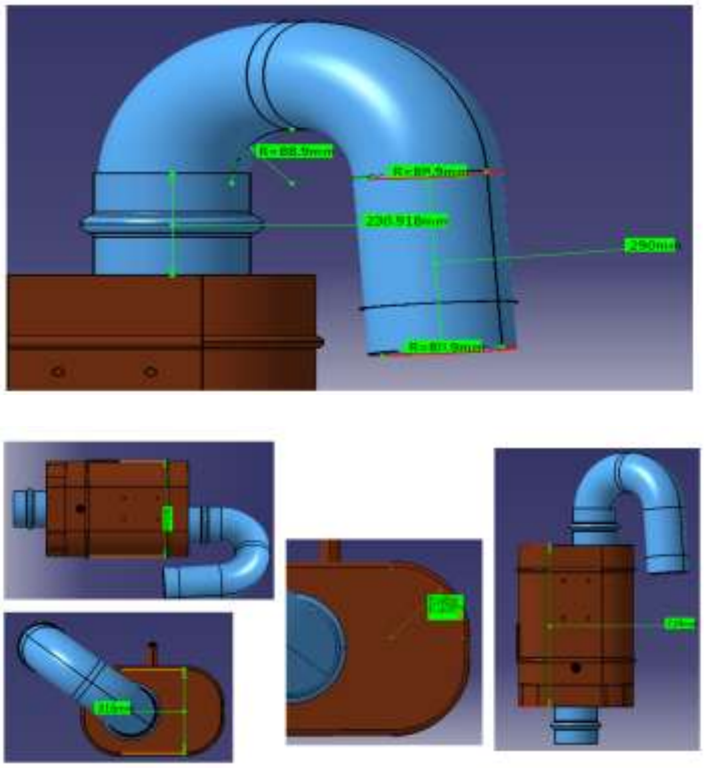

FIG-2: Dimensions of Base CAD Model

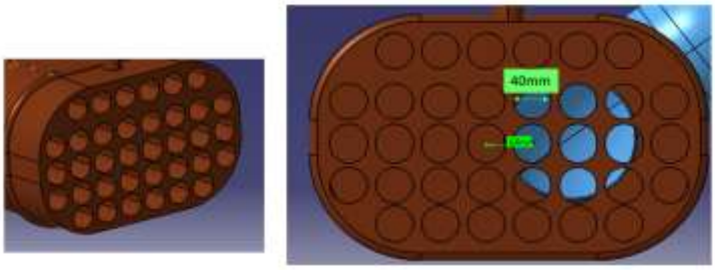

FIG-3: Dimensions of Honeycomb Structure

2.3 Meshing: Only internal wetted surfaces were extracted from for CFD domain and same is meshed in ANSYS Workbench.

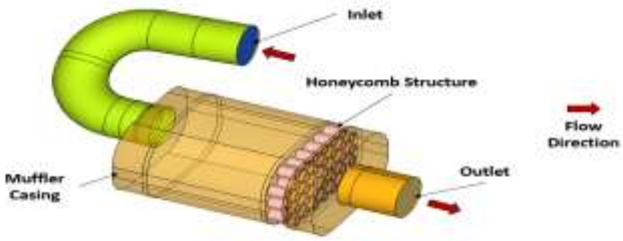

FIG-4: Internal wetted surface

1. CFD domain from Catalytic converter geometry is extracted as shown in above image.
2. Only wetted surfaces (Internal surfaces of geometry which are in contact with air) are considered for CFD domain.
3. Actual Inlet is extended further by 3D (D= Inner diameter of pipe) distance to develop uniform flow profile on actual inlet and actual outlet is extended further by 5D (D= Inner diameter of pipe) distance to avoid recirculation of flow on actual outlet side.

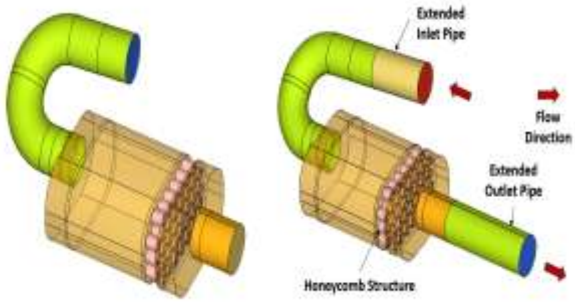

FIG-5: Internal wetted surface.

2.4 Boundary Conditions

Table- 1: -Cell Zone Conditions

Location	Material	Value
Fluid	Mixture of CO & Air	Density = 0.7534 kg/m³ Viscosity = 3.0927e-05kg/m-s
Honeycomb Structure	Wall	No Slip
Casing	Wall	No Slip
Outlet	Static Pressure Outlet	@ 0Pa
Fluid	Air	Density = 0.7534 kg/m3 Viscosity = 3.0927e-05 kg/m-s

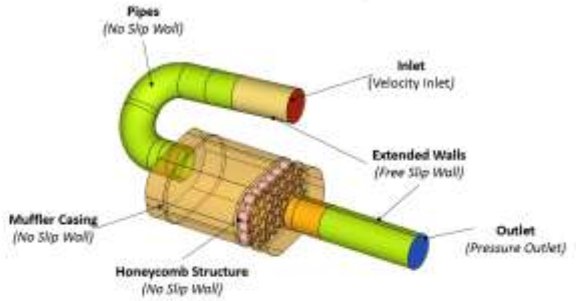

FIG-6: Boundary Conditions

2.5 Assumptions for simulation

- Flow is assumed steady flow.
- The fluid entering inside domain through inlet is considered as uniform.
- It is assumed that material property of fluid is isotropic in all regions.

3. POST PROCESS

3.1 Monitor Planes

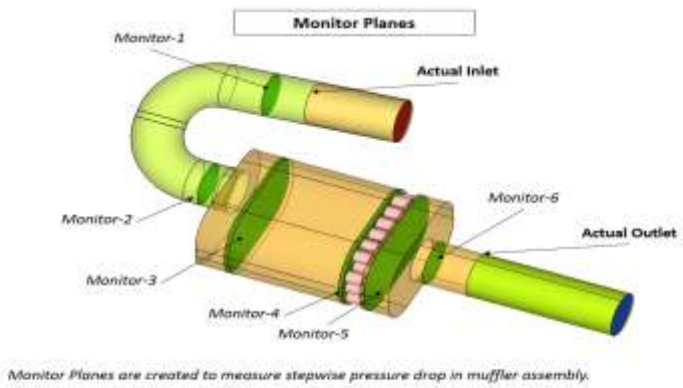

FIG-7: Monitor Planes.

Table-2: Results of CFD of Base Case Design

Location	Condition	Value
Inlet	Velocity	24.3m/s (Calculated based on 1150CFM)

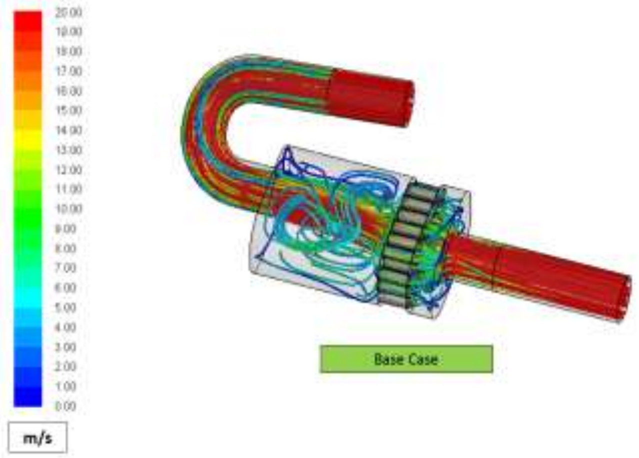

FIG-8: Path lines Colored by Velocity from Inlet (Clipped between 0 to 20m/s)

Table-3: Pressure Details at Monitors

	Base Case	
Plane Name	**Static Pressure**	**Total Pressure**
Actual Inlet	404.69138	627.10547
Monitor-1	400.47125	622.71185
Monitor-2	341.47348	578.57361
Monitor-3	335.16193	482.18069
Monitor-4	424.97644	480.58905
Monitor-5	280.18768	329.38605
Monitor-6	-64.428528	239.09216
Actual Outlet	-21.034731	222.58826

Table-4: Location Wise Pressure Drop in Catalytic converter:

	Base Case	
Plane Name	**Static Pressure**	**Total Pressure**
Actual Inlet to Monitor-1	4.22013	4.39362

Monitor-1 to Monitor-2	58.99777	44.13824
Monitor-2 to Monitor-3	6.31155	96.39292
Monitor-3 to Monitor-4	-89.81451	1.59164
Monitor-4 to Monitor-5	144.78876	151.203
Monitor-5 to Monitor-6	344.616208	90.29389
Monitor-6 to Actual outlet	-43.393797	16.5039

3. MODIFICATIONS IN BASE DESIGN

3.1 Design of Honeycomb structure

It is observed that flow is not uniformly distributed inside casing which is diverted on one side and this is because of inlet pipe center offset. There is sudden expansion happening in casing and inlet pipe junction which can be avoided with conical section of pipe on inlet side. Flow should be uniformly distributed inside casing to spread it on cross section of honeycomb. Because very less resistance on honeycomb major amount of flow is passing through middle section of honeycomb, to spread flow uniformly over honeycomb diameter of holes need to be change and inlet pipe has to be shifted to center along with conical pipe section at entry of casing. It is also observed that pressure loss after honeycomb is higher because of sudden contraction happening at outlet-casing junction and hence to avoid this honeycomb structure needs to be shifted at center of casing and conical pipe needs to be created on outlet side.

There are few modifications done in diameter of holes of honeycomb, thickness of honeycomb, and after observing results of all these cases, final modifications were done on Catalytic converter.
Results of other modification cases are given in consecutive sections.

3.1.1 Modifications in Hole Diameter of Honeycomb Structure.

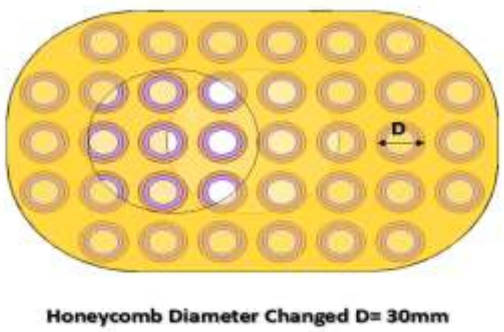

FIG-9: Honeycomb Structure Hole Diameter

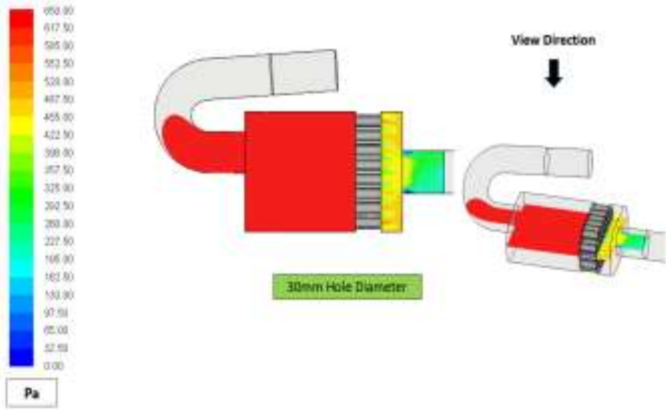

FIG-10: Pressure Contours on Y-1 (Clipped between 0 to 650Pa)

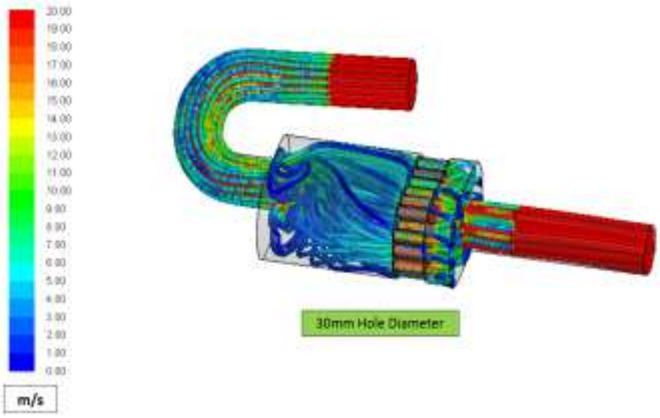

FIG-11: Path lines Colored by Velocity from Inlet (Clipped between 0 to 20m/s)

Table-5 Pressure Details at Monitors

Modification-(30mm Hole Diameter)		
Plane Name	**Static Pressure**	**Total Pressure**
Actual Inlet	575.0208	797.4808
Monitor-1	565.2078	787.9839
Monitor-2	327.8708	728.1329
Monitor-3	498.8495	621.9846
Monitor-4	556.9218	644.3903
Monitor-5	149.7731	280.6453
Monitor-6	-19.7479	208.5859
Actual Outlet	-1.2609	199.2653

Table-6 Location Wise Pressure Drop in Catalytic converter

Modification-(30mm Hole Diameter)		
Plane Name	**Static Pressure**	**Total Pressure**

Actual Inlet to Monitor-1	15.2266	5.7131
Monitor-1 to Monitor-2	97.6553	31.9055
Monitor-2 to Monitor-3	-60.0095	184.9677
Monitor-3 to Monitor-4	10.9456	52.0119
Monitor-4 to Monitor-5	334.4313	238.1883
Monitor-5 to Monitor-6	316.4973	198.2641
Monitor-6 to Actual outlet	58.0755	78.4855

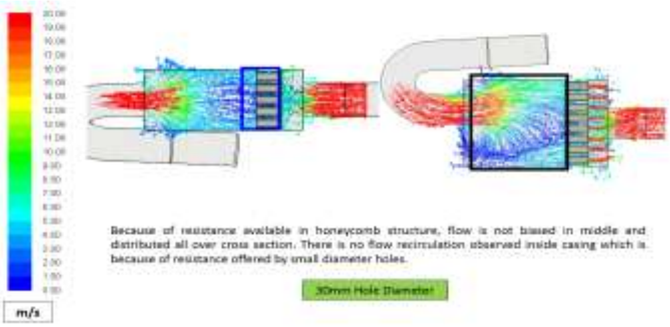

FIG-12: Velocity Vectors on Z-1 & Y-1

(Clipped between 0 to 20m/s)

It is observed that flow is distributed across cross section of honeycomb and pressure drop across honeycomb has increased as compared to base case which is because of resistance of small holes. Flow uniformity has improved but pressure drop is increased. To compensate pressure drop and increase flow uniformity inside casing following modification can be combined together:

1. Shifting honeycomb structure at mid of casing length to avoid sudden contraction effect on outlet side.
2. Shifting inlet pipe at centre of casing to spread flow uniformly inside casing.
3. Reducing honeycomb hole diameter from 400mm to 30mm to increase resistance slightly and spread flow across cross section of honeycomb.
4. Addition of conical section on inlet & outlet side to avoid sudden contraction 7 expansion effects.

3.1.2 Modifications at Inlet and Outlet

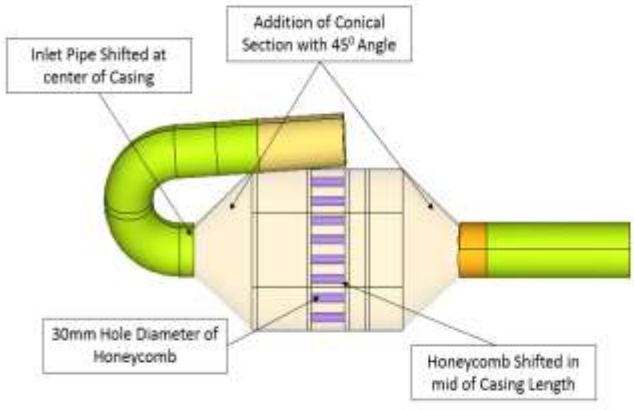

FIG-13: Modifications at Inlet and Outlet

Table-7 Results of CFD of Modification-4 Design

Boundary Conditions

Location	Condition	Value
Inlet	Velocity	24.3m/s (Calculated based on 1150CFM)
Honeycomb Structure	Wall	No Slip
Casing	Wall	No Slip
Outlet	Static Pressure Outlet	@ 0Pa
Fluid	Air	Density = 0.7534 kg/m3 Viscosity = 3.0927e-05 kg/m-s

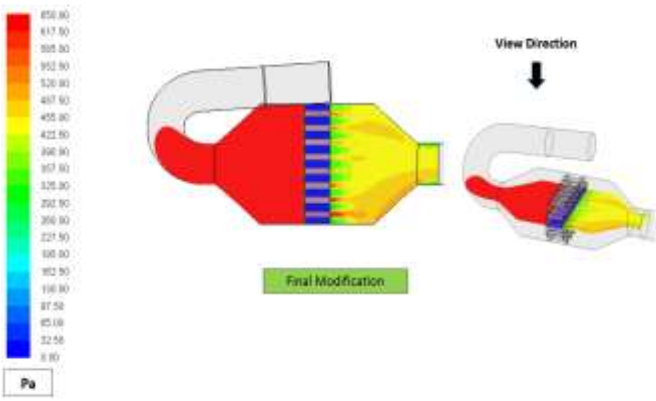

FIG-14: Pressure Contours on Y-1 (Clipped between 0 to 650Pa)

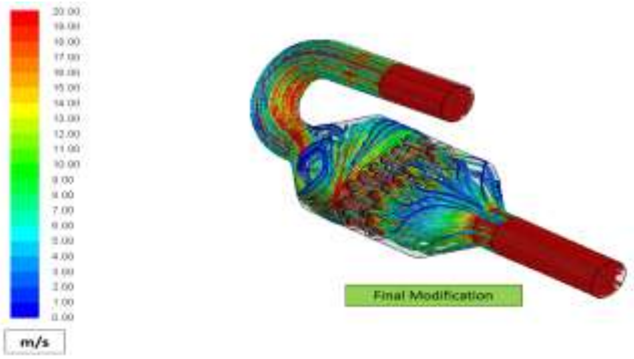

FIG-15: Path lines Colored by Velocity from Inlet (Clipped between 0 to 20m/s)

Table-8 Pressure Details at Monitors

Modification-4 (Final Modification)		
Plane Name	**Static Pressure**	**Plane Name**
Actual Inlet	575.0208	Actual Inlet
Monitor-1	565.2078	Monitor-1
Monitor-2	530.1500	Monitor-2
Monitor-3	498.8495	Monitor-3
Monitor-4	474.5689	Monitor-4
Monitor-5	285.6889	Monitor-5
Monitor-6	250.3586	Monitor-6
Actual Outlet	239.5680	Actual Outlet

Table-9 Location Wise Pressure Drop in Catalytic converter

Modification- (Final Modification)		
Plane Name	**Static Pressure**	**Total Pressure**
Actual Inlet to Monitor-1	9.8130	9.49688
Monitor-1 to Monitor-2	35.05782	59.85096
Monitor-2 to Monitor-3	31.30054	106.1484
Monitor-3 to Monitor-4	24.28056	16.94106
Monitor-4 to Monitor-5	188.88	254.3545
Monitor-5 to Monitor-6	35.3303	68.2993
Monitor-6 to Actual outlet	10.7906	16.8051

4. OBSERVATION

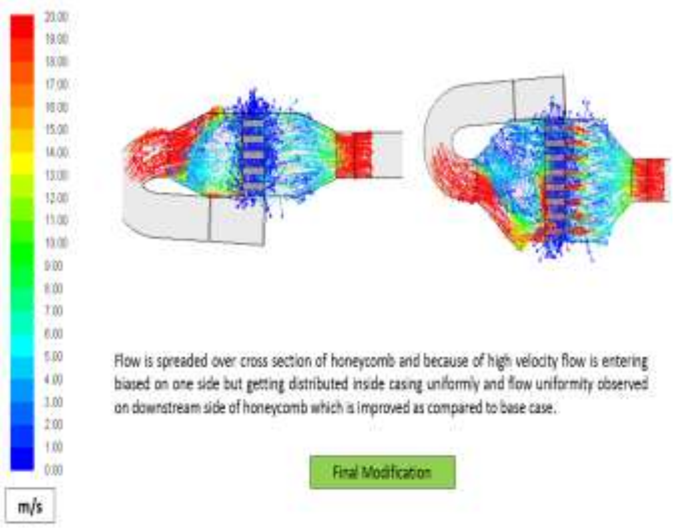

FIG-16: Velocity Vectors on Z-1 & Y-1 (Clipped between 0 to 20m/s)

Flow profile has improved inside casing after modifications and also pressure drop is reduced successfully. Major recirculation zones are eliminated after modifications and this modified case is working better than base case design and hence position of honeycomb, Inlet-Outlet Pipe locations, Pipe & casing junctions and honeycomb holes/porosity are important parameter which will decide back pressure on engine parts. After carrying out CFD analysis design modifications were done and pressure drop and recirculation zones/dead zones are eliminated to use honeycomb structure efficiently.

This modified design is simulated to check effectiveness of the system to absorb CO present in exhaust gases. The case-2 results are provided in consecutive section.

5. CARBON MONOXIDE ABSORPTIVITY PROFILE

Table-10 Boundary Conditions

Location	Condition	Value
Inlet	Velocity	24.3m/s (Calculated based on 1150CFM)
Honeycomb Structure	Porous Zone & Source Term	Pressure Drop vs Velocity Curve
Casing	Wall	No Slip
Outlet	Static Pressure Outlet	@ 0Pa
Fluid	CO & Air Mixture	Density = Incompressible Ideal gas Viscosity = 1.72e-05 kg/m-s

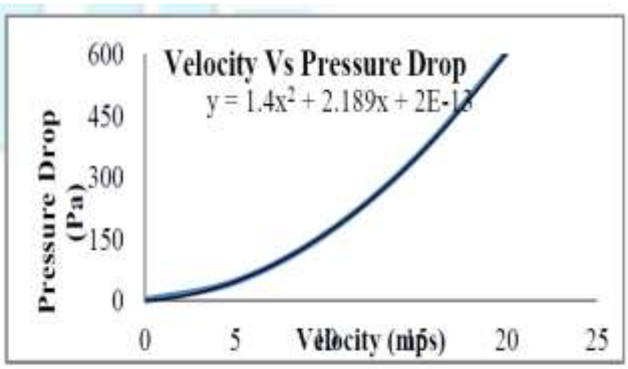

FIG-17: Pressure drop v/s Velocity Curve of Honeycomb Structure.

Honeycomb structure is made up of porous holes which allow flow passing through with some pressure drop and can trap particles inside porous and can absorb species. Modeling micro level porous holes in CFD models can increase element count by huge margin which will need very high configuration computers to solve the case and hence to avoid generation of high count elements. Porous media approach is used for the CFD simulation model.

The separate element volume is created of same size of honeycomb structure and porous media properties are applied for mesh volume. Porous properties consist of viscous resistance coefficient and inertial resistance coefficient. This viscous and inertial resistance is calculated from Pressure drop V/s Velocity curve which is referred from "DESIGN ANALYSIS OF FLOWCHARACTERISTICS OFCATALYTIC CONVERTER AND EFFECT OF BACK PRESSURE ON ENGINE PERFORMANCE, by kuruppusamy Pitchai". The calculated viscous and inertial resistance coefficient are applied on porous volume in fluent which will trap the species and source term option is turned in a cell zone condition which will allow absorption in the honeycomb structure.

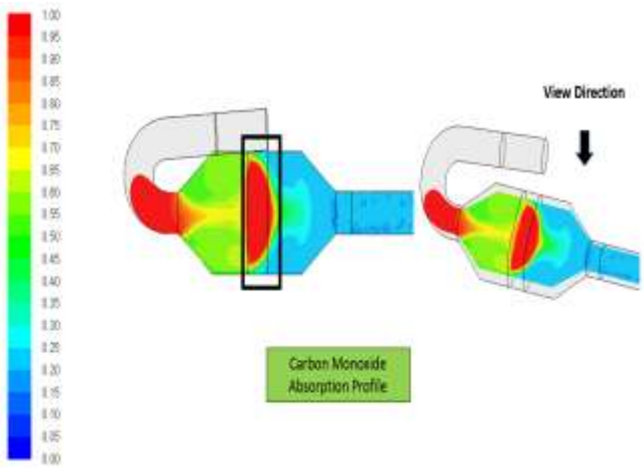

FIG-18: Mass Fraction of CO on Y-1

The mass fraction value of CO is higher inside honeycomb volume (Highlighted under black colored box) which is because of source term in that volume which is absorbing CO in that region and trapping the species. Mass fraction of Co emitted is ~0.25.

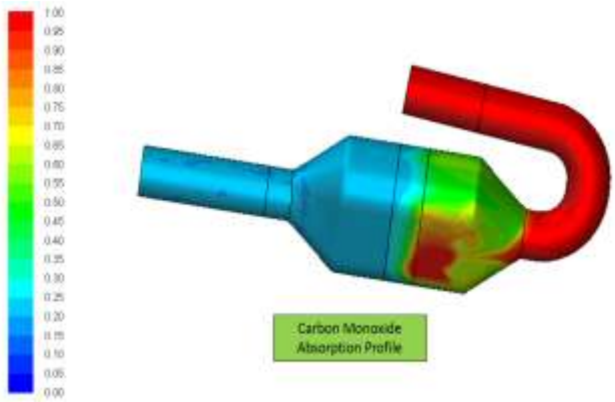

FIG-19: Mass Fraction of CO on Y-1

The mass fraction of CO is higher inside pipe which is then diffused inside casing and dropped after passing through honeycomb structure. Mass fraction of Co emitted is ~0.25.

Observation: It is observed that modifications made in the design are allowing flow to spread uniformly inside casing and utilizing overall region of honeycomb structure. Honeycomb structure is absorbing the CO and mass fraction of CO emitted is less than 0.25 which is good performance. The back pressure effect has reduced along with uniform profile and increasing absorptive of honeycomb and design.

6. CONCLUSION

With the current research on catalytic converters, it is possible to for now a days where automobiles are no longer known to pollute and damage the environment. As well as being environmentally friendly, the automobile industry will benefit from this new catalytic converter. Automobile manufacturers will no longer be responsible for so much environmental damage due to the advanced catalytic converter. It is also applicable on the low temperature operated vehicles (such as like CNG etc.). By absorbing CO2, it is praise for our environment and could not be responsible for environmental aspects.

In more addition, further future research scope also available for reading catalytic converter that automobile vehicles' engine many non-user friendly gases produced but here only consider three main gases (such as like CO, NO_x, HC etc.) which were spread the emissions in higher rates, whereas it has some more non-user friendly gases (such as like SO2, PM10, PM2.5 etc.) which fallen out from the engine in small amounts. Thus we can make this device more accurate and pollution issues through automobile vehicles will be eliminated.

References

[1]L. venktesh, N. Dinesh "Control and reduction of emission using catalytic converter." – International research general of engineering and technology. (2017)
[2]Anupam mukharji, Kunal Roy, Konika Mondal Catalytic converter in automobile exhaust emission- general for research vol.2 (2016)
[3]Prashant Katara. "Review paper on catalytic converter for automobile exhaust emission." – International journal of science and research (2015)
[4]Patil Ajinkya B. Shinde Rajaram M. "Development of catalytic converter for emission control of stationary diesel engine" – Technical research organization India. (2015)
[5]P. Karuppusamy, dr. R. senthil. "Design analysis of flow characteristics of catalytic converter and effect of back pressure on engine performance. "– IJREAT vol.1 (2013)
[6]S.K.Sharma, P.Goyal, S.Maheshwari, A.Chandra "A Technical Review Of Automobile Catalytic Converter: Current Status And Perspectives"- STOCEI-A Sustainable Approach (2013)
[7]Yash Sudhirkumar trivedi, "Design of an Automobile Exhaust System With Catalytic converter and Method of preparation there of ",-IERJ Page no.1668-1672
[8]B.Balakrishna, S. Mamaidala, "Design Optimization of Catalytic Converter to reduce Perticulate Matter and Achieve Limited Back Pressure in Diesel Engine in CFD"-IJOCET (2014)