MINOR PROJECT REPORT

Design and Analysis of Catalytic Converter

Submitted by

Aadarsh Kumar (UE219001)

Chekit Sharma (UE219016)

Gulammoin Uddin (UE219027)

Gyandeep Kumar Yadav (UE219028)

Supervisor:

Mr. Harbhinder Singh

(Asstt. Professor)

Signature

CERTIFICATE

I hereby certify that the work which is being submitted in this project report titled '**Design and Analysis of Catalytic converter'**, in partial fulfilment of the requirement for the award of degree of 'Bachelors of Engineering in Mechanical Engineering' submitted at UIET, Panjab University, Chandigarh, is an authentic record of my own work carried out under the supervision of Mr. Harbhinder Singh and refers to others' work which are duly listed in the reference section. It is further certified that the report has also been thoroughly checked on anti-plagiarism software. The matter present in the report has not been submitted for the award of any other degree of this or any other university.

Aadarsh Kumar
(UE219001)

Chekit Sharma
(UE219016)

Gulammoin Uddin
(UE219027)

Gyandeep Kumar Yadav
(UE219028)

Mr. Harbhinder Singh,
Asstt. Professor,
Dept. of Mech. Engg.,
UIET, Panjab University,
Chandigarh - 160014

Acknowledgement

First and foremost, we are deeply thankful to our project guide Ass. Professor Mr. Harbhinder Singh for his guidance, encouragement, and constructive feedback throughout the project. His expertise and support were invaluable in overcoming challenges and achieving our objectives. We are also grateful to our college UIET, Panjab University, Chandigarh for providing the resources, infrastructure, and a conducive environment for the project. The support from the administrative and technical staff was crucial in ensuring a smooth workflow.

Finally, we would like to thank ur families and friends for their constant encouragement and understanding during this period.

This project's completion marks a significant milestone, and we are grateful for the opportunity to learn, grow, and contribute meaningfully through this endeavour.

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Abstract

Automobiles throughout the world are the primary consumers of fossil fuels, which emit toxic gases when burnt; including HC, CO and NOx. Catalytic converters were developed to detoxify these gases into less harmful gases such as carbon dioxide and H2O. OEM catalytic converters are built for commercial vehicles and use noble elements including, Platinum (Pt), Palladium (Pd) and Rhodium (Rh).

One of the aim of this study is to develop a catalytic converter with available elements other than noble elements, which cost much higher. The catalytic converter has been specifically designed for a Hero Single Cylinder 99.7 CC engine used to power motorcycles like Splendor. The main objective of this study was to observe pressure drop for different converter designs with respect to geometry configuration of the catalytic converter and different cell shapes and honeycomb structure of the Catalytic Converter.

OBJECTIVES

A Catalytic Converter is device that is used to reduce pollutants and toxic gases in the exhaust gas from the combustion engine by chemical reactions is known as a catalytic converter. These converters need a temperature of 426-degree centigrade so that it can convert harmful gases into non-toxic gases, so these are placed as close as possible to the engine to get enough temperature which it requires. These converters are mostly used in automobiles, but their application has also been increased in mining equipment, generators, etc. where the amount of harmful gas emission is high.

1.1 Objectives:

1. To design a conventional catalytic converter for a single cylinder motorcycle engine and improve the performance of conventional catalytic converter by changing its design criteria.
2. To determine the pressure variation and overall pressure drop due to change in geometry of inlet cone shell of catalytic converter.
3. To check the effect of change in mesh design of honeycomb structure in catalytic converter.

1.2 The steps to be taken are:

1. To study the design and working of Catalytic Converter.
2. Designing catalytic converter chamber while considering engine specification.
3. Creating 3D models using CAD software. .
4. Perform Computational Fluid Dynamics using Ansys Discovery.
5. Result and visualization.

INTRODUCTION

2.1 Introduction to Vehicle emission:

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. 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 and copper** 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.

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. It is a simple device that uses basic redox reaction to reduce the pollutants.

2.2 Functions of Catalytic converter:

catalytic converter has three simultaneous functions:

1. Reduction of nitrogen oxides into elemental nitrogen and oxygen:

$$NO_x \rightarrow N_x + O_x$$

2. Oxidation of carbon monoxide to carbon dioxide:

$$CO + O_2 \rightarrow CO_2$$

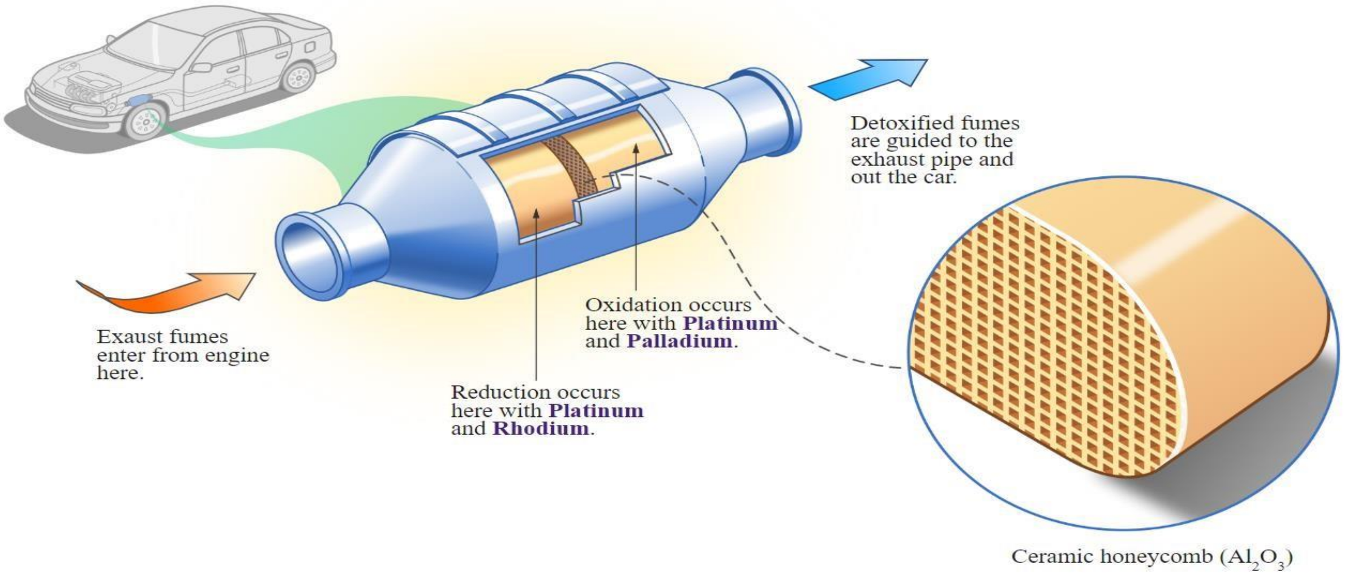
3. Oxidation of hydrocarbons into carbon dioxide and water:

$$C_xH_{4x} + 2xO_2 \rightarrow xCO_2 + 2xH_2O$$

(a)

(b)

Fig.1- (a) Catalytic Converter (b) Catalytic converter installed in vehicle



DESIGN PROCESS

The objective of this study was to determine the effect of geometry of the inlet cone of the catalytic converter on the pressure drop and to study pressure variation along the length in the catalytic converter. Two cell shapes namely square and hexagonal and having common cell areas of 6.25 mm^2 are considered for the study. CFD analysis is used to observe the pressure drop in both of the shapes.

The catalytic converter chamber was designed while considering the engine specifications which are as follows:

3.1 Specifications:

- Engine considered = Hero Single Cylinder 97.2 cc air cooled

Specifications	Values
Swept Volume	100 cc
Engine speed(N)	2000 RPM
Bore Diameter(d)	50 mm
Stroke(L)	49.5 mm

- For Single Cylinder,
  Space velocity = 30000 hr^{-1}

3.2 Calculations:

Volume flow rate = Swept Volume × No. of intake strokes

$$= \left(\frac{\pi}{4} \times d^2 \times L\right) \times \left(\frac{N}{2} \times 60\right)$$

$$= \left(\frac{\pi}{4} \times 50^2 \times 49.5\right) \times \left(\frac{2000}{2} \times 60\right)$$

$$= 5.83\ \frac{m^3}{hr}$$

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

$$= \frac{5.83}{30000}$$
$$= 0.00014\ m^3$$

Shell Dimensions:

For L=2D

Catalyst Volume = Area × Length

$$0.00014 = \frac{\pi}{4} \times D^2 \times 2D$$

D = 49.8 mm

L = 99.6 mm

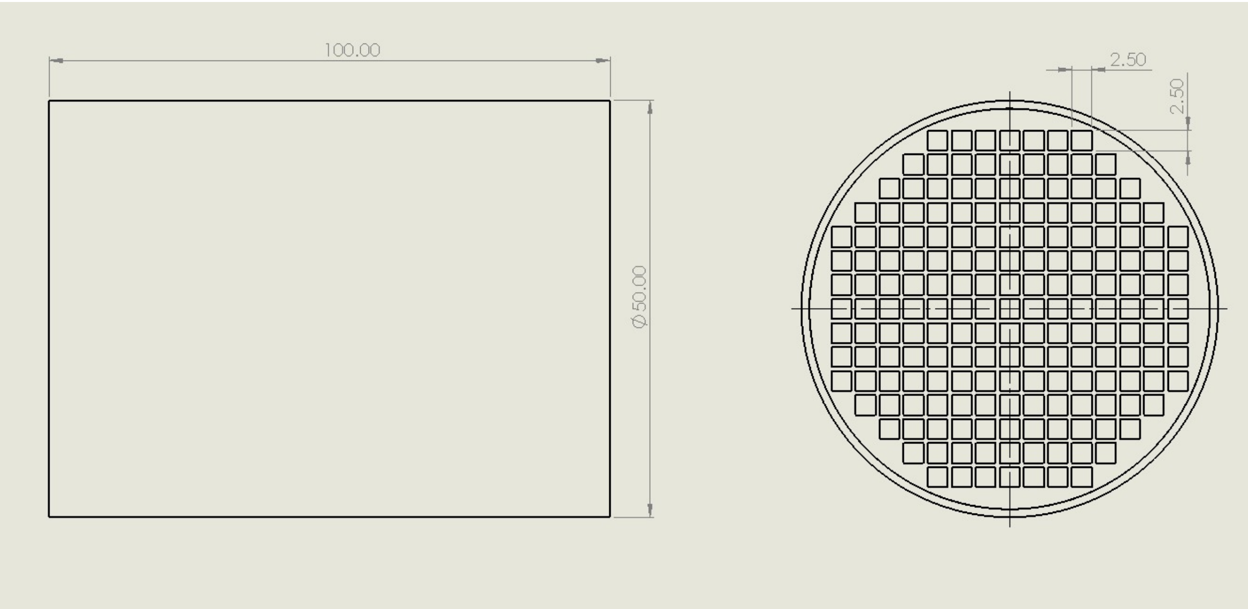


Fig 2. Square Mesh design

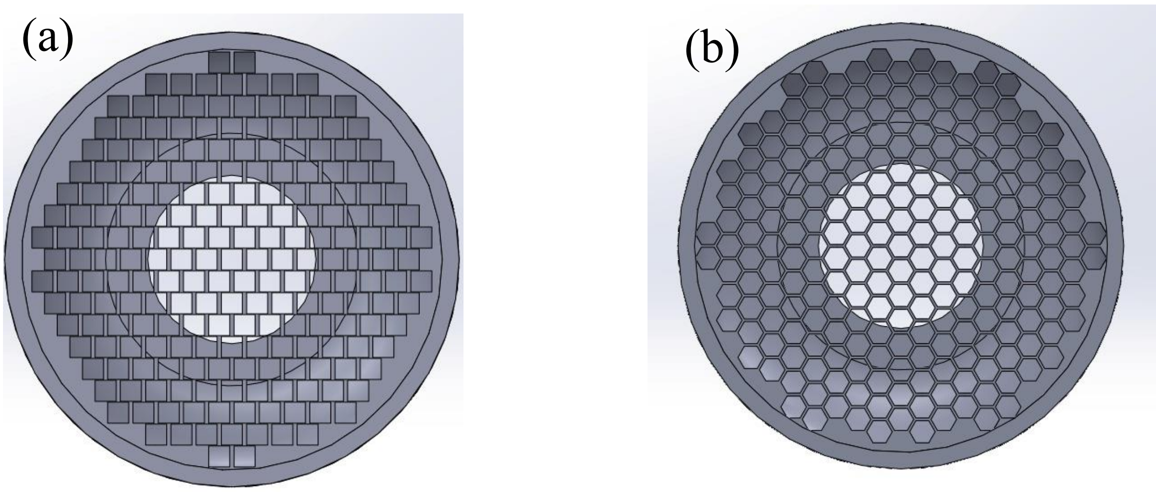


Fig 3. (a) Square mesh structure (b) Hexagonal mesh structure

CAD DESIGN

4.1 Cases Considered:

CAD modelling of Catalytic converter is done in **SolidWorks**. We have considered three geometric configuration of inlet cone shell of catalytic converter:

1. 10° Cone Angle
2. 20° Cone Angle
3. 30° Cone Angle

4.2 Designs:

The figures shows drawing of the models of Catalytic Converter:

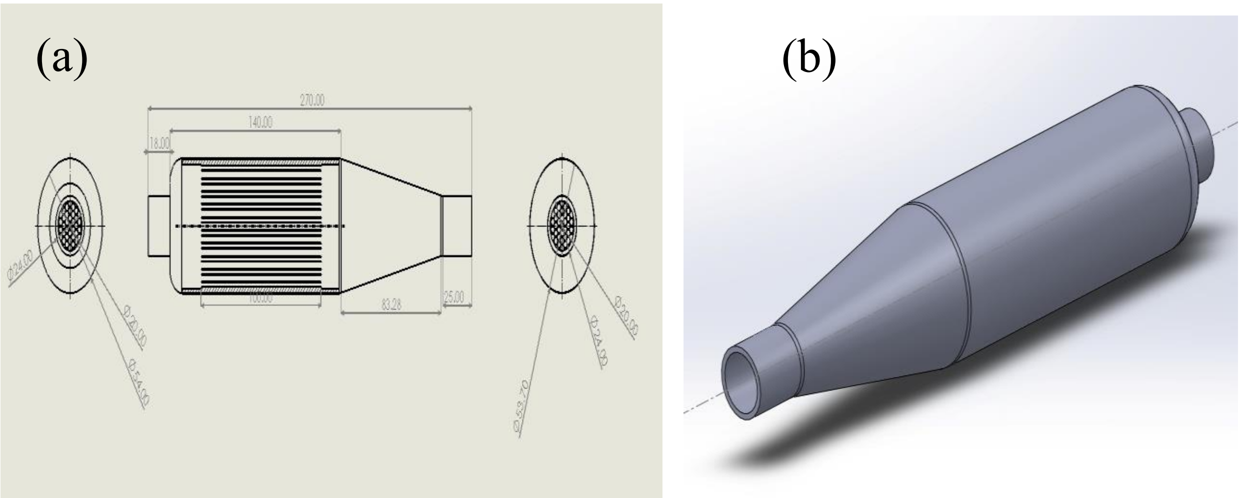


Fig 4- (a) 2D Design and (b)3D design of 10° Cone Angle

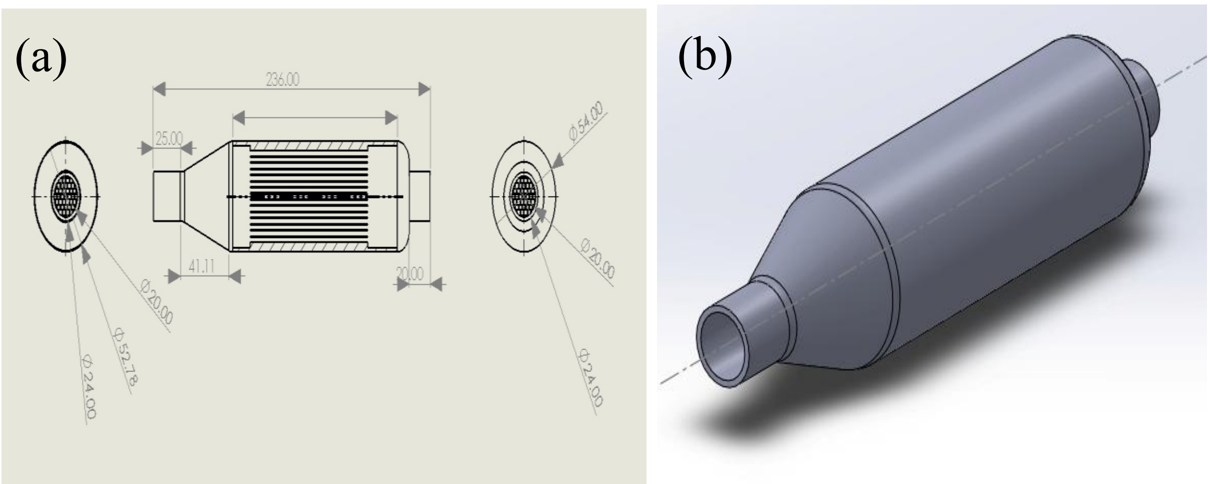
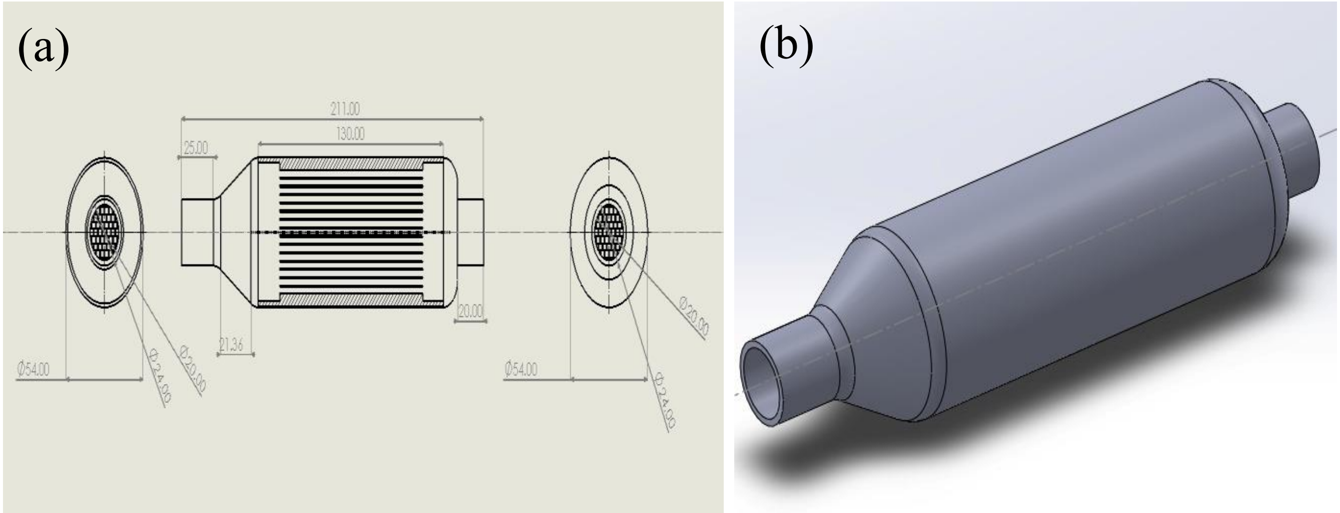
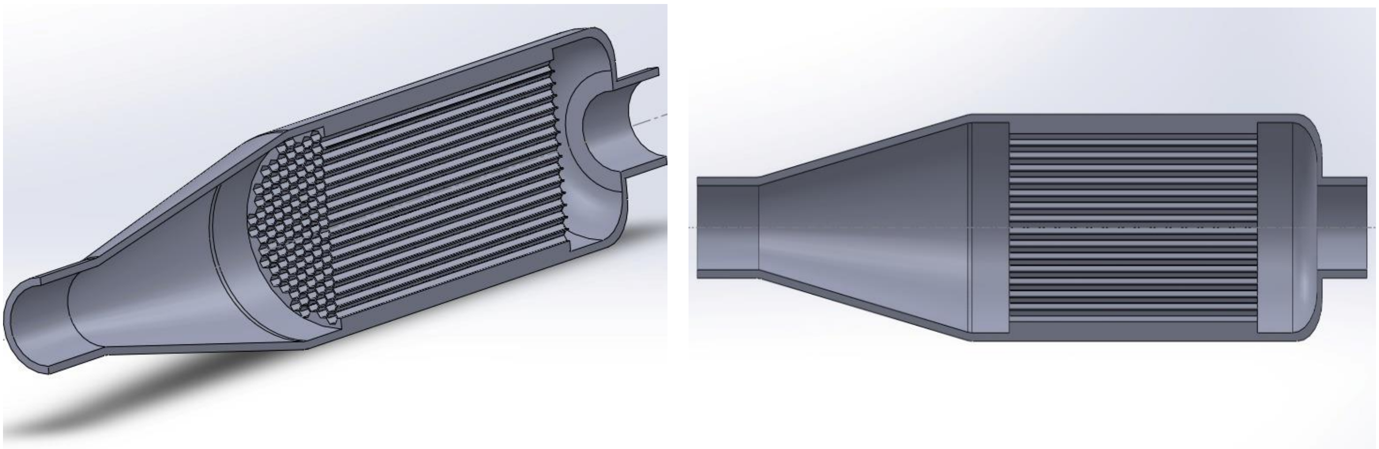


Fig 5- (a) 2D Design and (b)3D design of 10° Cone Angle



<u>Fig 6-</u> (a) 2D Design and (b)3D design of 10° Cone Angle

<u>4.3 Sectional View of Mesh Structure of Catalytic Converter:</u>



<u>Fig 7-</u> Section View of Catalytic Converter

CFD ANALYSIS SETUP

Only internal wetted surfaces were extracted from for CFD domain and same is meshed in ANSYS Discovery.

5.1 Instruction:

1. CFD domain from Catalytic converter geometry is extracted as shown in fig. 3.
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 D(D= Inner diameter of inlet pipe) distance to develop uniform flow profile on actual inlet and actual outlet distance to avoid recirculation of flow on actual outlet side.

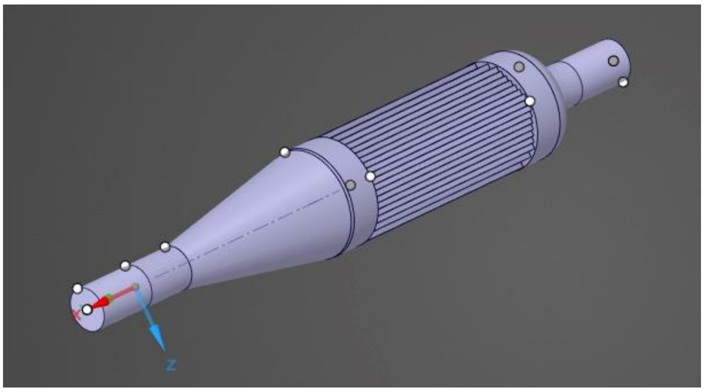
Table 1- Boundary Conditions

LOCATION	Condition	VALUE
Inlet	Mass flow rate	0.0012 kg/hr
Honeycomb Structure	wall	No Slip
Casing	wall	No Slip
Outlet	Static Pressure Outlet	0 Pa
FLUID	Mixture of CO and Air	Density=0.7534 kg/m^3 Viscosity=3.0927e-05 kg/m-s

5.2 Assumption for the simulation:

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

(a)



(b)

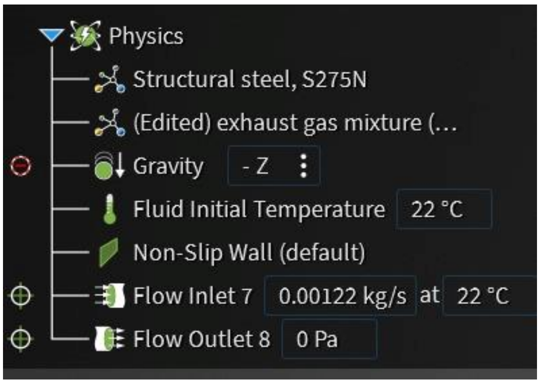


Fig.8 (a) Internal wetted surface and extended inlet and outlet

(b) Boundary Conditions

POST PROCESSING AND RESULTS

6.1 Case 1- Geometric Configuration of Catalytic Converter:

We have considered three geometric cases :

1. 10° Cone Angle
2. 20° Cone Angle
3. 30° Cone Angle

The inlet cone angle of a catalytic converter plays a significant role in determining the efficiency of exhaust flow distribution, pressure drop, and overall catalytic performance.

(1) Flow distribution:

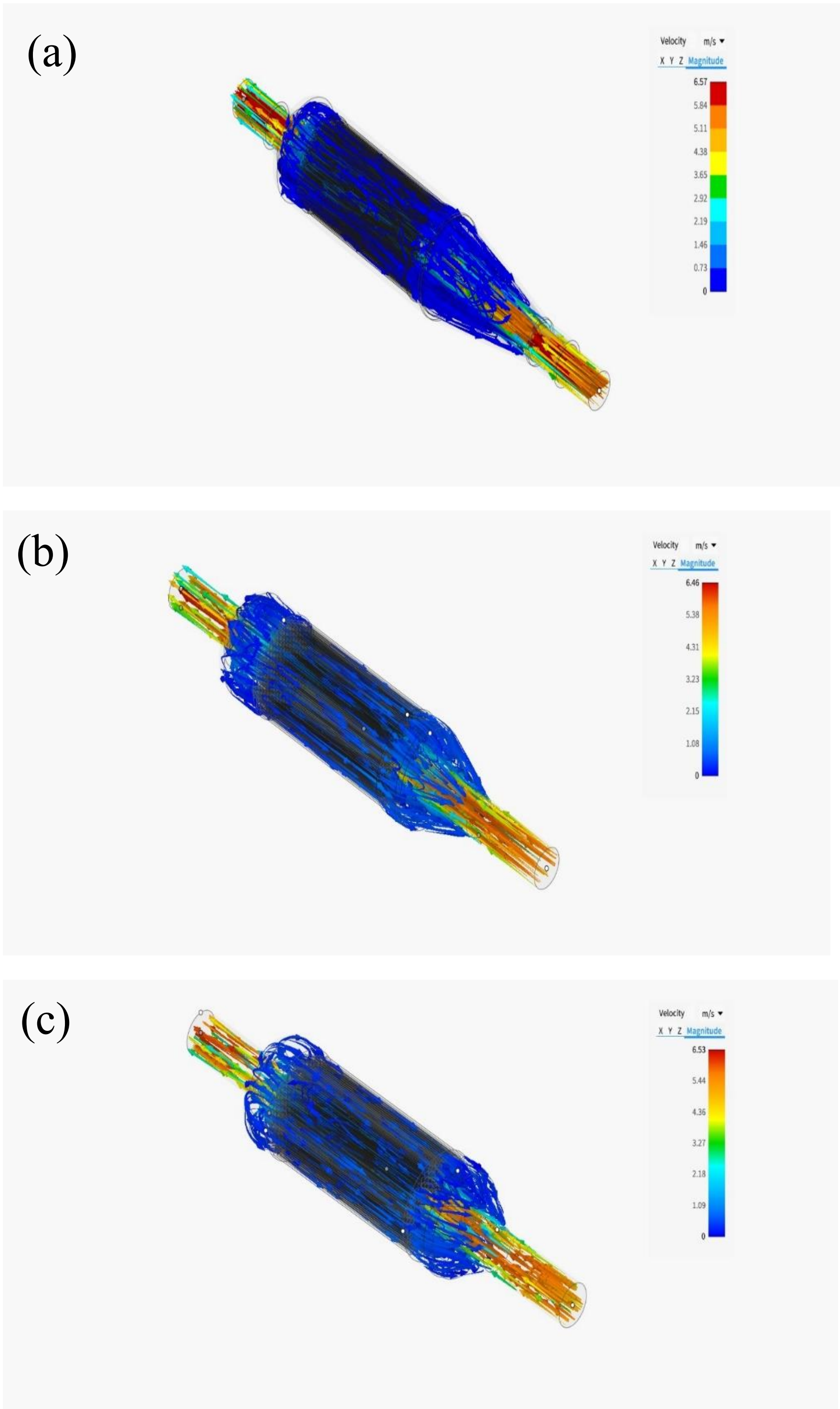
A well-designed inlet cone angle ensures uniform distribution of exhaust gases across the monolith (honeycomb structure) of catalytic converters.
Wide Cone Angle: May result in turbulent flow, uneven distribution, and dead zones in the monolith, reducing the converter's efficiency.
Narrow Cone Angle: May lead to higher velocities and a concentrated flow, which might not fully utilize the entire surface area of the monolith.

(2) Pressure drop:

The inlet cone angle affects the backpressure in the exhaust system:
Steeper Angles: Tend to cause a higher pressure drop due to abrupt changes in velocity and direction, leading to inefficiencies in the engine.

Gentler Angles: Provide a smoother transition for exhaust gases, minimizing pressure drop and improving overall system performance

The Fig. 9 shows the flow distribution inside the catalytic converter for different geometric considerations taken for the observation purpose.



<u>**Fig.9 –**</u> Path lines of the flow (a)10° (b) 20° (c) 30° Cone Angle

Table 2:- Pressure drop between inlet and outlet of Catalytic Converter

Case	Pressure drop
10° Cone Angle	13 Pa
20° Cone Angle	14 Pa
30° Cone Angle	15 Pa

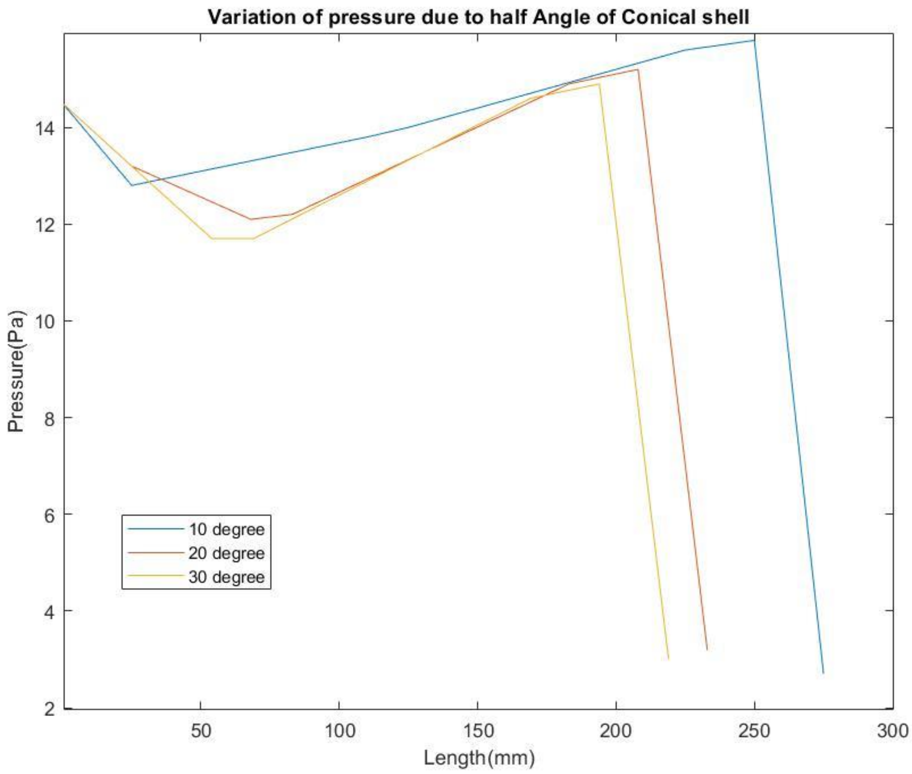


Fig.10 – Pressure Variation along the length of Catalytic Converter for different inlet cone angle

Observation and result:

From the data collected we observe that the pressure drop is minimum in case of 10° Cone Angle and maximum in 30° Cone Angle Catalytic Converter and Flow distribution is also more uniform in 10° Cone Angle compared to other cases.

The order of pressure drop is,

30° Cone Angle>20° Cone Angle>10° Cone Angle

Hence, for further analysis we will consider 10° Cone Angle geometric configuration of the Catalytic Converter.

6.2 Case 2- Mesh Design and cell shape of the Honeycomb Structure:

The geometry of the cells in the honeycomb structure affects surface area, flow dynamics, and catalytic efficiency. Common shapes include square and hexagonal cells.

Square cells:

Advantages:

(1) Easy to manufacture.
(2) Provides a balance between surface area and flow resistance.

Disadvantages:

(1) Slightly less surface area per unit volume than hexagonal cells.

Hexagonal Cell:

Advantages:

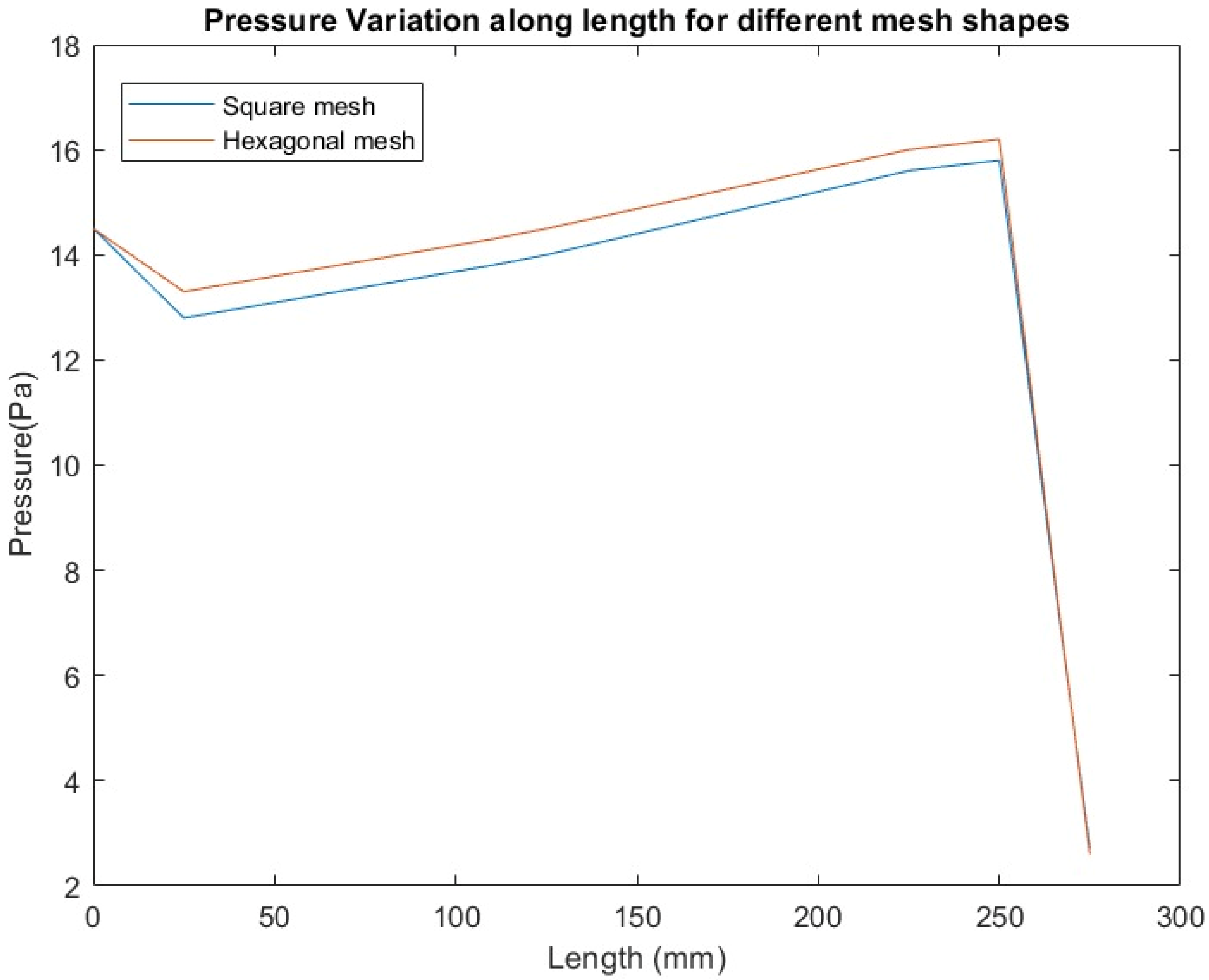
(1) Maximize Surface area per unit volume.
(2) Excellent flow uniformity and efficient catalytic reaction.

Disadvantages:

(1) More challenging to manufacture than square cells.

To perform the study we have taken the area of each cell as common parameter for the cell shapes for the comparison purpose. The area taken is 6.25 mm^2 for each cell.

The Fig.11 shows the pressure variation inside the catalytic converter for different cell shapes and mesh desig taken for the observation purpose.



<u>Fig.11 –</u> Pressure Variation along the length of Catalytic Converter for different cell shapes and mesh design

Table 3- Change in pressure drop, number of cells and surface area with respect to cell shape

Specifcation	Square cell	Hexagonal cell
Cell size	Side length= 2.5 mm	Side length= 1.55 mm
Cell area	6.25 mm^2	6.25 mm^2
Number of cells	215	223
Surface area	134375 mm^2	139375 mm^2
Pressure drop	13 Pa	13.6 Pa

Result and Conclusion:

From the data collected we observed that

- the surface area of catalyst is more for Hexagonal cell by about 4%.
- The number of cells is also more for Hexagonal cells which makes it more suitable for faster catalytic reaction.
- The pressure drop is less for the square cell compared to hexagonal cell making it mire suitable for better flow.

So, From these observation we conclude that

- Hexagonal cells are better than Square cells for Catalytic reaction due to availability of more surface area for the reaction to take place.
- Spare cells are good for balance between flow distribution and catalyst reaction.

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