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Optimum Modeling of Catalytic Converter for Limited Back Pressure

N. Suresh Babu[1], D. Ramesh Babu[2], Dr.M.Mastanaiah[3]

[1] *M.Tech student, Thermal Engineering, Department of Mechanical Engineering, Dr. Samuel George Institute of Engineering and Technology, Markapur, Prakasam D.T, A.P*

[2] *Associate Professor, Department of Mechanical Engineering, Dr. Samuel George Institute of Engineering and Technology, Markapur, Prakasam D.T, A.P*

[3]*Professor, Department of Mechanical Engineering, Dr. Samuel George Institute of Engineering and Technology, Markapur, Prakasam D.T, A.P*

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Abstract - These days the level of harmful gases has been increasing in the atmosphere. This growth in pollutants causes a great change in global climate patterns. The emissions from automobiles have become the prime reason for green house effect. In order to reduce the emissions released out of vehicles a device termed as catalytic converter is installed in them. A Catalytic converter is a simple pollution minimizing unit that helps in eliminating the dangerous gases like CO, unburnt HC, NOX etc. This converter is used to convert toxic fumes delivered by an engine into less-toxic fumes like H_2O, CO_2, N2 respectively. Still it increases the exhaust backpressure. Basically, the enhancement of backpressure causes an additional consumption of fuel and minimizes break thermal efficiency which results in poor performance of the vehicle. The exhaust backpressure can be shortened by considering a proper inlet cone angle.

In this project, the study of seven designs of catalytic converters and their modeling was carried out by changing the inlet cone angle. The main objective of this paper is to obtain the optimum inlet cone angle which produces the minimum backpressure. With the help of CATIA software, the design of seven catalytic converters was done. The flow analysis was executed in ANSYS FLUENT software by taking suitable boundary conditions and fluid properties into consideration. Eventually, Computational Fluid Dynamic analysis was also performed on these models and the results of backpressures of seven models were also compared.

Keywords: Catalytic converter, Emissions, Backpressure, ANSYS

I. INTRODUCTION

The catalytic converter or 'Cat-Con' is a mechanical device. It reduces the harmful emissions created in the exhaust system of an engine. It is an important device as it works with the harmful gases, which the engine creates during combustion of fuel. The main purpose of a catalytic converter is to reduce exhaust emissions Out of various technologies available for automobile exhaust emission control a catalytic converter is found to best option to control CO, HC and NOx emissions from petrol driven vehicles while diesel particulate filter and oxidation catalysts converter or diesel oxidation catalyst have so far been the most potential option to control particulates emissions from diesel driven vehicle. A catalytic converter (CC) is placed inside the tailpipe through which deadly exhaust gases containing unburnt fuel, CO, NOx are emitted. The function of the catalytic convertor is to convert these gases into CO2, water, N2 and O2 and currently, it is compulsory for all automobiles plying on roads in US and Japan to have catalytic converters as they use unleaded petrol. In India the government has made catalytic converters mandatory for registration of new cars.

1.2 TYPES OF CATALYTIC CONVERTERS

1.2.1 Two-Way Catalytic Converter

- Oxidation of carbon monoxide to carbon dioxide: $2CO + O2 \rightarrow 2CO2$
- Oxidation of hydrocarbons (unburnt and partially burnt fuel) to carbon dioxide and water: (a combustion reaction)

Fig 1.1 Two-way catalytic converters

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This type of catalytic converter is widely used on diesel engines to reduce hydrocarbon and carbon monoxide emissions. Because of their inability to control oxides of nitrogen, they were superseded by three-way converters.

1.2.2 Three-way catalytic converter

A three-way catalytic converter has three simultaneous tasks:

- Reduction of nitrogen oxides to nitrogen and oxygen: $2NO_x \rightarrow xO_2 + N_2$
- Oxidation of carbon monoxide to carbon dioxide: $2CO + O_2 \rightarrow 2CO_2$
- Oxidation of unburnt hydrocarbons (HC) to carbon dioxide and water.

These three reactions occur most efficiently when the catalytic converter receives exhaust from an engine running slightly above the stoichiometric point. This point is between 14.6 and 14.8 parts air to 1 part fuel, by weight, for gasoline. In general, engines fitted with 3-way catalytic converters are equipped with a computerized closed-loop feedback fuel injection system using one or more oxygen sensors, though early in the deployment of three-way converters, carburetors equipped for feedback mixture control were used.

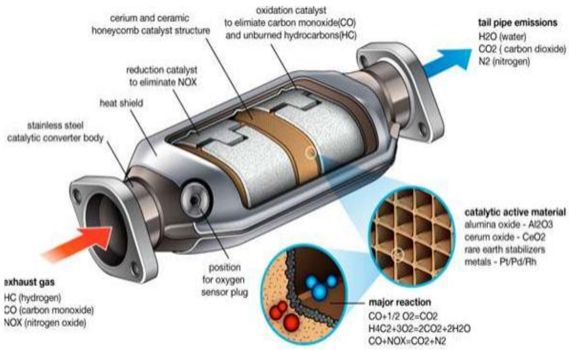

Fig 1.2 A Three-way catalytic converter

Three-way catalysts are effective when the engine is operated within a narrow band of air-fuel ratios near stoichiometry, such that the exhaust gas oscillates between rich (excess fuel) and lean (excess oxygen) conditions. However, conversion efficiency falls very rapidly when the engine is operated outside of that band of air-fuel ratios. Under lean engine operation, there is excess oxygen and the reduction of NOx is not favored. Under rich conditions, the excess fuel consumes all of the available oxygen prior to the catalyst, thus only stored oxygen is available for the oxidation function. Closed-loop control systems are necessary because of the conflicting requirements for effective NOx reduction and HC oxidation.

1.2. Effects of Backpressure

While back pressure considerations have always been faced by designers of exhaust systems, increased interest in exhaust pressure has been caused by fitting diesel engines with diesel particulate filters, and the introduction of complex after treatment systems in general. Installation of DPFs often raises concerns about increased exhaust back pressure. Increased exhaust pressure can have a number of effects on the diesel engine, as follows:

- Increased pumping work
- Reduced intake manifold boost pressure
- Cylinder scavenging and combustion effects
- Turbocharger problems

At increased back pressure levels, the engine has to compress the exhaust gases to a higher pressure which involves additional mechanical work and/or less energy extracted by the exhaust turbine which can affect intake manifold boost pressure. This can lead to an increase in fuel consumption, PM and CO emissions and exhaust temperature. The increased exhaust temperature can result in overheating of exhaust valves and the turbine. An increase in NOx emissions is also possible due to the increase of engine load.

II. MODELING OF CATALYTIC CONVERTER BY CATIA

CATIA is 3D modeling software used in mechanical engineering, design, manufacturing, and in CAD drafting service firms. It was one of the first 3D CAD modeling applications that used a rule-based parametric system. Using parameters, dimensions and features to capture the behavior of the product, it can optimize the development product as well as the design itself. The name was changed in 2010 from CATIA Wildfire It was announced by the company who developed it, Parametric Technology Company Dassault systems, during the launch of its suite of design products that includes applications such as assembly modeling, 2D orthographic views for technical drawing, finite element analysis and more.

In the present work basic model of the catalytic converter was modeled and by changing the cone inlet angle, there are seven models were modeled by using CATIA.

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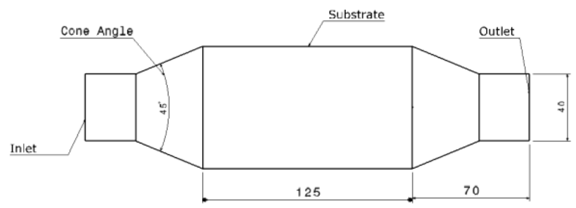

Fig 2.1 : Two dimensional view of catalytic converter

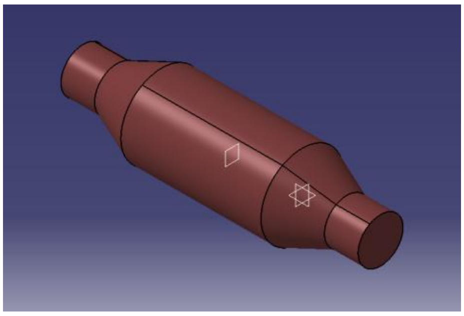

Fig 2.2 : 3D model of the catalytic converter

Model no	Cone Inlet angle(degree)
1	30
2	35
3	40
4	45
5	50
6	55
7	60

Table 2: Parameters of different models

The seven models with cone inlet angle 30^0, 35^0, 40^0, 45^0, 50^0, 55^0 and 60^0 were modeled individually in CATIA and exported in to ANSYS for flow analysis.

III. CFD ANALYSIS OF CATALYTIC CONVERTER

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. With high-speed supercomputers, better solutions can be achieved. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. Initial experimental validation of such software is performed using a wind tunnel with the final validation coming in full-scale testing, e.g. flight tests.

3.1 Modeling: The modeling of catalytic converter was already done in CATIA.Model was exported as .stp formate and imported into ANSYS Fluent for making flow analysis.

3.2 Meshing: A tetrahedral mesh with fine coarse size was selected to perform smooth and fine mesh

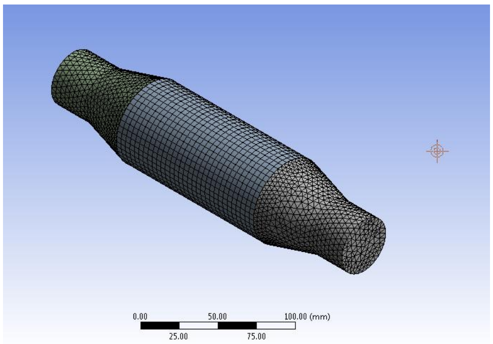

Fig 3.1 : Meshed model of catalytic converter

3.3 Boundary conditions: Inlet velocity of 20 m/s was applied at the inlet and a gauge pressure of 0 pas was applied at the outlet of the model.

IV. RESULTS

Flow analysis of catalytic converter was done by considering the above conditions. The main aim of this work is to reduce exhaust backpressure. So the seven models were analyzed and the pressures at different locations, velocities were calculated and they are shown in the following figures.

4.1 Model 1 Results

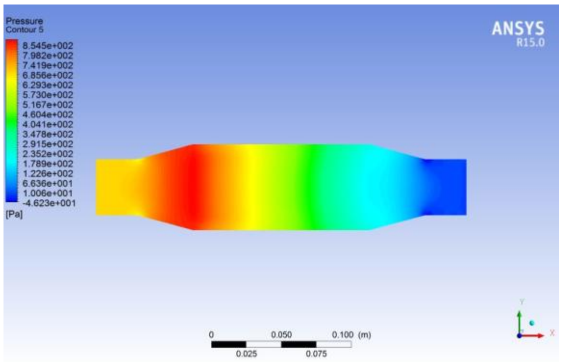

Fig 4.1 : Pressure distribution in Model-1

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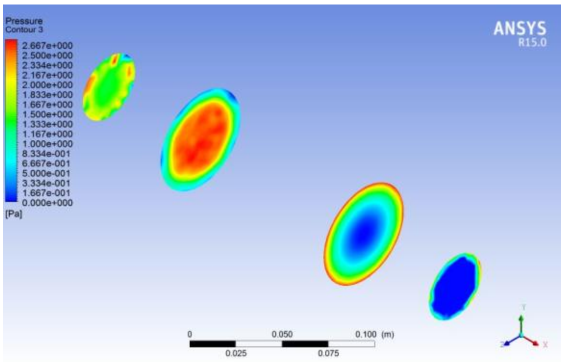

Fig 4.2: Pressure distribution in model-1 at catalytic converter inlet, substrate inlet, substrate outlet and catalytic converter outlet

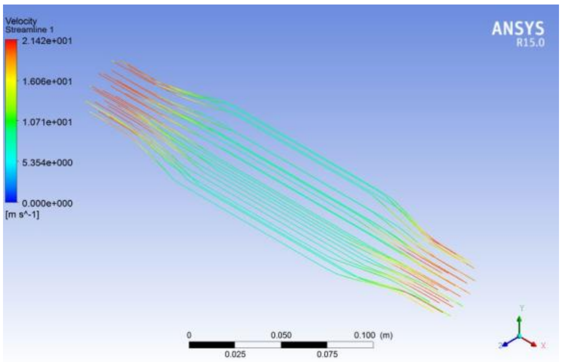

Fig 4.3: Velocity streamlines in Model-1

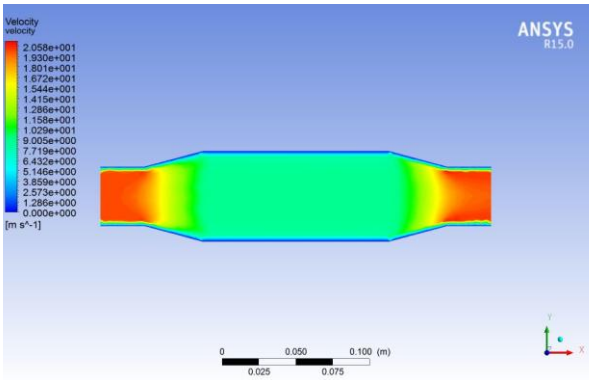

Fig 4.3: Velocity distribution in Model-1

4.2 Models-2 Results

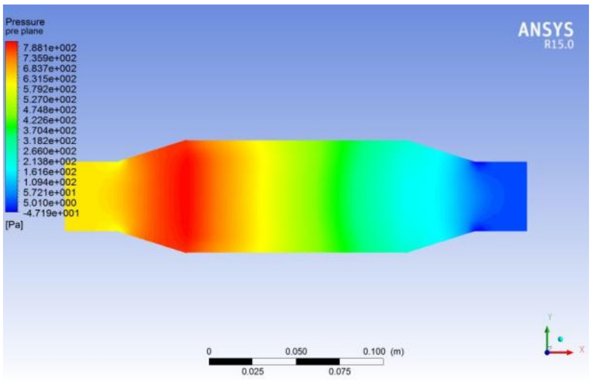

Fig 4.3: Pressure distribution in Model-2

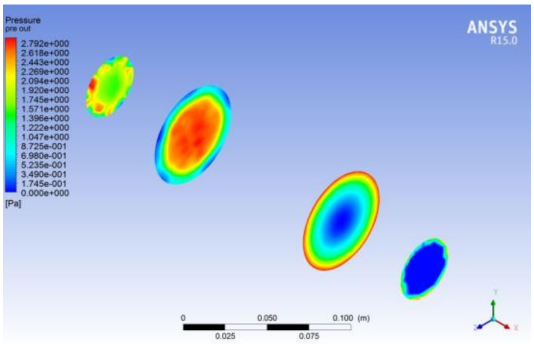

Fig 4.4: Pressure distribution in model-2 at catalytic converter inlet, substrate inlet, substrate outlet and catalytic converter outlet

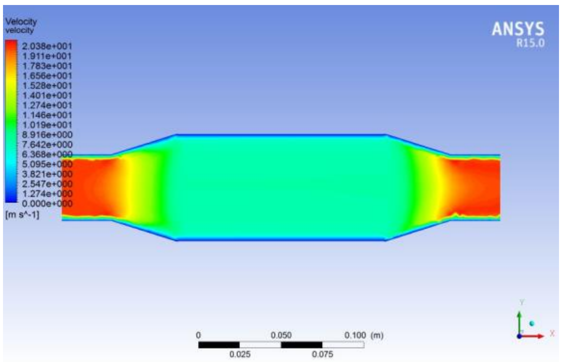

Fig 4.5: Velocity distribution in Model-2

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4.3 Model-3 Results

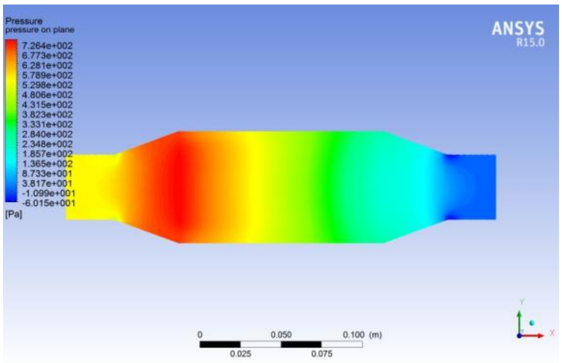

Fig 4.6: Pressure distribution in Model-3

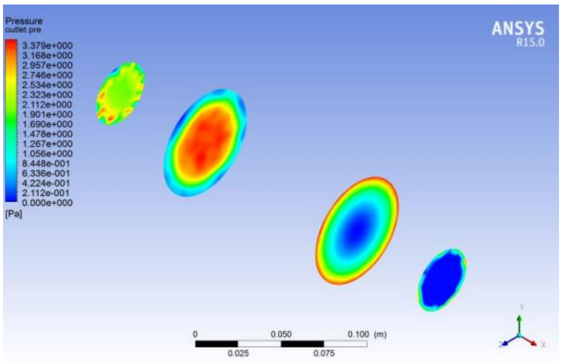

Fig 4.7: Pressure distribution in model-3 at catalytic converter inlet, substrate inlet, substrate outlet and catalytic converter outlet

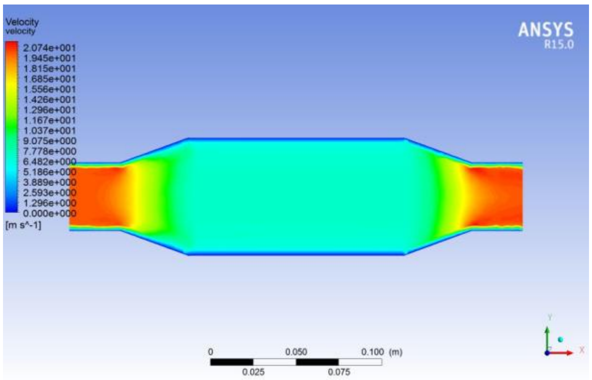

Fig 4.8: velocity distribution in Model-3

4.4 Model-4 Results

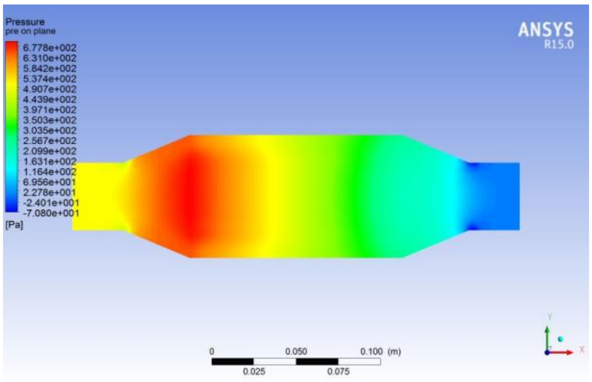

Fig 4.9: Pressure distribution in Model-4

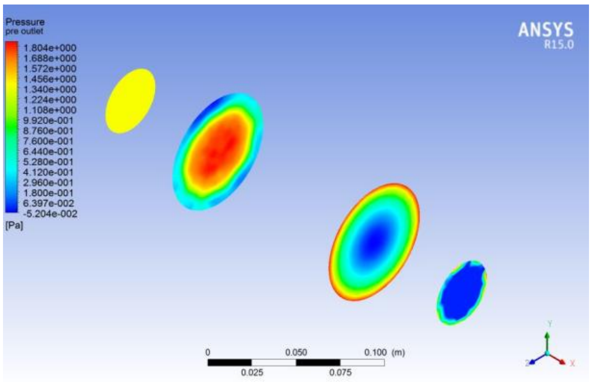

Fig 4.10: Pressure distribution in model-3 at catalytic converter inlet, substrate inlet, substrate outlet and catalytic converter outlet

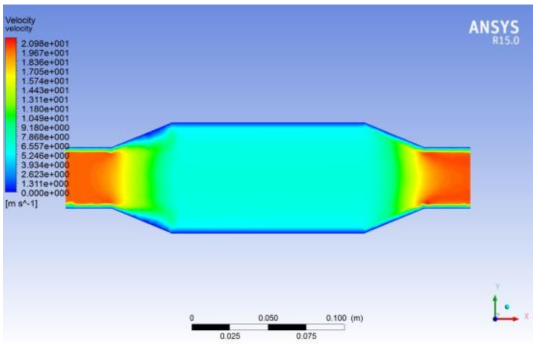

Fig 4.11: Velocity distribution in model-4

Similarly the remaining models were also analyzed and their results are shown in the following table.

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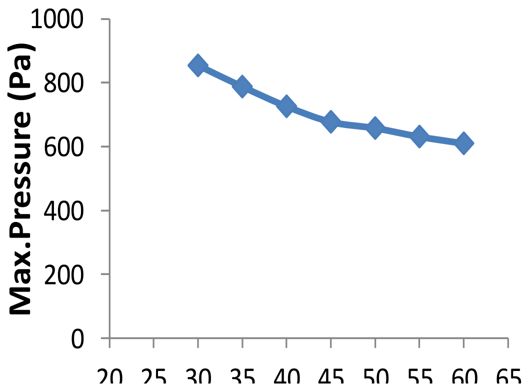
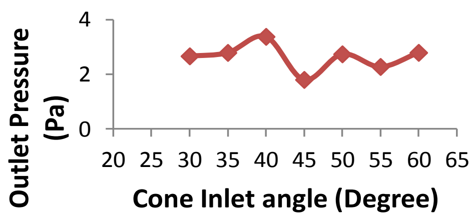
Inlet cone angle	Max. pressure (Pa)	Pressure at inlet (Pa)	Pressure at outlet (Pa)	Pressure at substrate inlet (Pa)	Pressure at substrate outlet (Pa)	Max. velocity (m/sec)
30^0	854.5	702.9	2.667	882.0	232.3	20.58
35^0	788.1	627.3	2.792	814.7	237.3	20.38
40^0	726.4	556.9	3.379	750.8	248.1	20.74
45^0	677.8	679.1	1.804	700.8	255.6	20.98
50^0	658.3	482.3	2.740	678.0	262.5	21.11
55^0	631.6	454.0	2.278	651.4	267.8	21.39
60^0	610.5	430.1	2.794	628.4	271.0	20.65

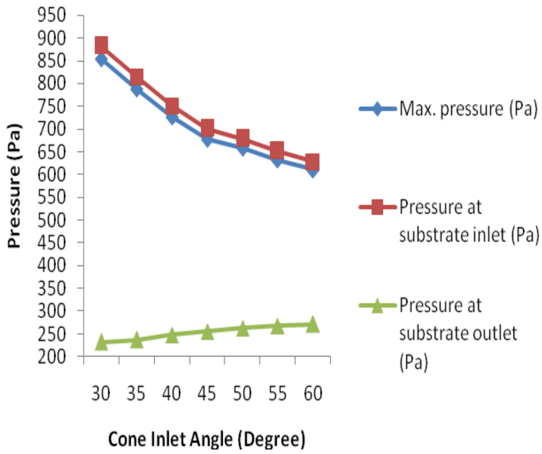
Table 1: pressure & velocities of different models



Graph 1: cone inlet angle Vs Max.pressure



Graph 2: cone inlet angle Vs Outlet Pressure



Graph 3: Cone inlet angle Vs pressures

Form the above results it was observed that the outlet pressure was increasing from model-1 to model-3, and was reduced for model-4. From model- 5 onwards again it was getting increased. Based on the above results the following conclusions were made.

V. CONCLUSIONS

The increasing level of today's automobile emissions has to be dropped as they are the major cause for environmental changes. It can be achieved by reducing the harmful pollutants leaving the engine by means of a catalytic converter. It is a device that converts toxic gases into less toxic gases but maximizes the exhaust backpressure. The main object of this work is to decrease the backpressure from the outlet of the converter. To achieve this goal, changing of inlet cone angle of converter can be helpful. Catalytic converter was designed and examined under Computational fluid dynamic analysis. Here, seven models of catalytic converters were modeled by altering the inlet angle of cone from the ranges of 30^0 to 60^0 with an increment of 5^0. Modeling of these seven converters was carried out by using CATIA software. Computational fluid dynamic analysis was also accomplished by considering appropriate fluid properties and boundary conditions. The values of pressures attained from the analysis of ANSYS Fluent software were noted down at catalytic converter inlet, substrate inlet, substrate outlet and catalytic converter outlet. From the analysis results were obtained and the values of backpressures of seven models were compared. It was clearly noted that the catalytic converter with an angle of 45^0 produces a minimum pressure of 1.804 Pa. And shows this model favors in achieving less consumption of fuel and better engine performance. In conclusion, it can be said that the cone inlet angle with 45^0 is the optimum catalytic converter that minimizes exhaust backpressure and improves the performance of engine.

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