

Backpressure Study in Exhaust Muffler of Single Cylinder Diesel Engine using CFD Analysis

P.S.R ANIL TEJA¹, Dr. K. HEMA CHANDRA REDDY²

¹PG Student, Dept of Mechanical engineering (AICE), JNTUA, AP, India.

² Professor, Dept of Mechanical engineering, JNTUA, AP, India

ABSTRACT:

Using diesel engines mostly as main power source has gained the importance in the recent years. Technical specification of the diesel engine and its components has been the main focus of the researchers. The muffler is defined as a device for reducing the amount of noise emitted by an engine. The muffler is engineered as an acoustic sound proofing device designed to reduce the loudness of the sound pressure created by the engine by way of Acoustic quieting. Due to increased environmental concerns requiring less noise emissions combined with reduced emission of harmful gases, it is becoming very crucial to carefully design the exhaust system mufflers for road transport applications.

INTRODUCTION:

In this Study comprehensively two different models of exhaust mufflers viz., reactive muffler and resonative mufflers are comprehensively analyzed to determine the best possible design for least pressure drop. Back pressure will be obtained based on the flow field analysis and compared with other muffler designs. Virtual simulation for back-pressure testing is performed by Computational Fluid Dynamic (CFD) analysis using Ansys CFD. Finite Element (FE) Model generation of the muffler structure is performed using Hyper Mesh as the preprocessor. The structural mesh is modeled using 2D shell elements, where in the internal tubes with fine perforated holes are considered. The CFD fluid meshing has been done with tetra elements using Ansys as the CFD preprocessor.

As a result the back pressure generated across the muffler is determined by measuring and inputting the mass flow rate of the exhaust gases entering the muffler inlet pipe. Field view is used for post processing the CFD results and reviewing the airflow streamlines. The exhaust gas velocity and pressure plots are plotted across the internal tubes and perforated holes, and hence the back pressure is measured.

THE MAIN OBJECTIVE OF THIS THESIS WORK:

- To find the relationship between the exhaust back pressure levels occurred in exhaust flow design as well as expansion chamber and yet propose the best design to ensure the optimization of engine performance.
- Comparing the obtained results with the other altered designs of mufflers to state the best possible design with least pressure drop.
- Ensuring the exhaust system components which are able to reject heat energy as intended by the original design.
- Providing adequate clearance between exhaust components and engine components, Machine structures, Engine bays, Enclosures and Building structures to reduce the impact of high exhaust temperatures on such items.

EXHAUST MUFFLER:

A muffler is a device for decreasing the amount of noise emitted by the exhaust of an internal combustion engine. Mufflers are installed within the exhaust system of most internal combustion engines, although the muffler is not designed to serve any primary exhaust function. The muffler is engineered as an acoustic soundproofing device designed to reduce the loudness of the sound pressure created by the engine by way of acoustic quieting. The majority of the sound pressure produced by the engine is emanated out of the vehicle via the same piping used by the silent exhaust gases. The emitted noise is abated by a series of passages and chambers lined with roving fiberglass insulation and/or resonating chambers harmonically tuned to cause destructive interference, wherein opposite sound waves cancel each other out. An unavoidable side effect of muffler use is an increase of back pressure, which decreases engine efficiency.

TYPES OF MUFFLERS

1. Dissipative (absorptive) silencer

An absorptive or dissipative muffler, as shown in Figure 1, uses absorption to reduce sound energy. Sound waves are reduced as their energy is converted into heat in the absorptive material. A typical absorptive muffler consists of a straight, circular and perforated pipe that is encased in a larger steel housing. Between the perforated pipe and the casing is a layer of sound absorptive material that absorbs some of the pressure pulses.

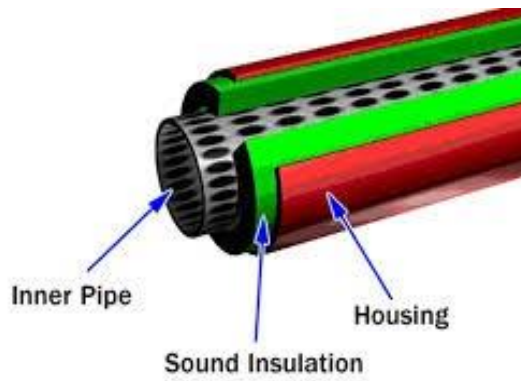


Figure 1. Perforated pipe with insulation and housing

2. Non Dissipative (Reactive) Muffler

The reactive or reflective mufflers use the phenomenon of destructive interference to reduce noise. This means that they are designed so that the sound waves produced by an engine partially cancel themselves out in the muffler. For complete destructive interference to occur a reflected pressure wave of equal amplitude and 180 degrees out of phase needs to collide with the transmitted pressure wave. Reflections occur where there is a change in geometry or an area discontinuity.

A reactive muffler, as shown in Figure 2, generally consists of a series of resonating and expansion chambers that are designed to reduce the sound pressure level at certain frequencies. The inlet and outlet tubes are generally offset and have perforations that allow sound pulses to scatter out in numerous directions inside a chamber resulting in destructive interference. Reactive muffler is revered for their ability to silence harsh engine noises. This uses engineered chambers with plates or perforated tubes, exhaust gets reflected from these plates and attenuation of sound happens. Reactive muffler works well in lower and mid-range frequencies but produce higher back pressure.



Figure 2 Cut view of a typical Reactive muffler

FUNCTIONAL REQUIRMENTS FOR DESIGNING AN ENGINE EXHAUST MUFFLER:

- Insertion Loss (IL)
- Transmission loss (TL)
- Back pressure:
- Size
- Durability
- Desired sound
- Cost
- Shape and Style

EXHAUST MUFFLER GRADES:

A muffler is to be designed, which is of supercritical grade type of making the muffler calculations have to use the exhaust muffler grades shown in the Table 3.1. In view of the above, in modeling a noise muffler it is essential to know not only the amount of exhaust noise reduction, but also the parameters of the system's operation speed after the noise muffler has been

installed. The mathematical model of an exhaust noise muffler developed is based on the equations of energy and compressed air motion in a pneumo system's elements. In developing the model following assumptions were taken:

- Consumption coefficients of all passage sections are constant
- There is no heat exchange with the environment
- The flow is one-dimensional
- Neglect of parameter distribution

Table 1 Exhaust muffler grades

Muffler grades	Insertion loss (IL)	Body/Pipe (in cm)	Length/Pipe (in cm)
Industrial/Commercial	15 - 25 dB	51 - 63.5	127 - 166
Residential grade	20 -30 dB	51 - 63.5	153 - 254
Critical grade	25 -35 dB	78	204 - 254
Super critical grade	35 - 45 dB	78	254 - 407

DESIGN CONSIDERATIONS:

i) Reactive muffler design consideration:

Table 2. Design data of reactive muffler

S.no	Description	Dimensions (mm)
1	Shell length and diameter	406 and 236
2	Inlet pipe length and dia	208 and 90
3	Outlet pipe length and dia	208 and 90
4	Perforated pipe diameter	60
5	Perforated hole diameter	15
6	Shell thickness	3

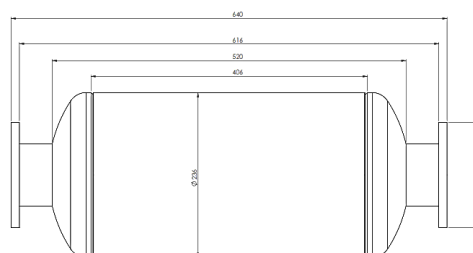


Figure 3 Reactive muffler design drafting

ii) Resonative muffler design consideration:

Table 4 Design data of reactive muffler

S.no	Description	Dimensions (mm)
1	Shell length and diameter	406 and 236
2	Inlet pipe length and dia	208 and 90
3	Outlet pipe length and dia	208 and 90
4	Perforated pipe diameter	60
5	Perforated hole diameter	15
6	Shell thickness	3

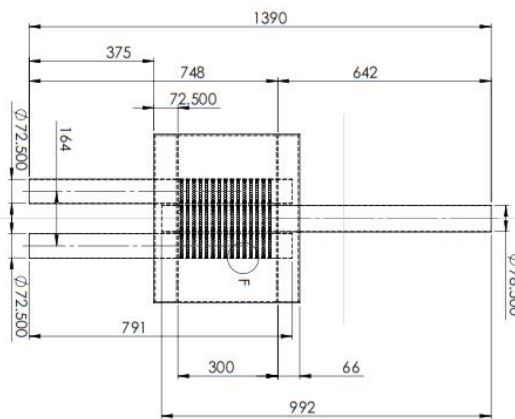


Figure 3.19 Resonative muffler design drafting

ENGINE PARAMETERS:

Back pressure study in Exhaust Muffler is done for a Single Cylinder Diesel engine. Input parameters like engine details, boundary conditions, fuel data and physical models required for defining problem are shown in following table.

For the below engine parameters the muffler geometry is developed using SOLID WORKS 2017 with the design parameters as discussed earlier for respective mufflers and taken it as case - 1 for analysis. Length of the chamber is translated with an incremental length of 5cm to the original designed chamber length and taken it to analysis as case - 2 and case - 3 with a decremented length of 5cm to the original designed chamber length. Remaining all other parameters of the design are kept constant as of original design in both reactive design as well as resonative mufflers.

Table 5.1 Engine details

Particulates	Specifications
Engine	KIRLOSKAR ENGINE
Type	Water-cooled
Ignition system	Compression ignition
Cylinder arrangement	Vertical
Maximum speed	1500 rpm
Number of Cylinder	1
Bore	85mm

Stroke	110mm
Compression Ratio	16.5:1
Maximum HP	5HP
Fuel	HSD

EXPERIMENTAL SETUP IN CFD:

Computational fluid dynamics (CFD) study of the system starts with the construction of desired geometry and mesh for modeling the dominion. Generally, geometry is simplified for the CFD studies. Meshing is the discretization of the domain into small volumes where the equations are solved by the help of iterative methods. Modeling starts with the describing of the boundary and initial conditions for the dominion and leads to modeling of the entire system. Finally, it is followed by the analysis of the results, conclusions and discussions.

CFD EXPERIMENTAL PROCEDURE

Step 1:

First, the fluid flow (fluent) module from the workbench is selected. The design modeler opens as a new window as the geometry is double clicked.

Step 2:

Import the saved 3D geometry STEP (.stp) file in the design modeler. Unwanted geometry features like flanges etc., which won't have worthwhile impact on CFD analysis have been removed. Checked for possible geometry interferences and performed Boolean operations to remove such errors and ensured that the geometry is air tight.

Step 3:

Fluid has been developed using Space claim module of the Ansys workbench

Step 4:

Geometry has been sliced in design modular buy using sliced plane by plane in order to have a sweepable meshing, however connectivity is maintained throughout the domain forming new part.

Step 5:

Checked for any interferences in the model as it may effect the meshing and repair the model if needed.

Step 6:

Finally group all the parts into one single file such that mesh connectivity exists between all the parts.

Step 7:

Save the project at this point and close the window. Refresh and update the project on the workbench.

Meshing:

A fine mesh is generated. For this fine mesh, the edges and regions of high pressure gradients are finely meshed. This mesh contains mixed cells Tetra cells all over the boundary. Care is taken to use structured mesh as much as possible. It is meant to reduce numerical diffusion as much as possible by structuring the mesh in a well manner, particularly near the wall region. Mesh size at different regions are taken as below.

Table 5.2 Mesh details

Parameters	Values
Element size (near holes)	3mm
Element size (near walls)	10mm

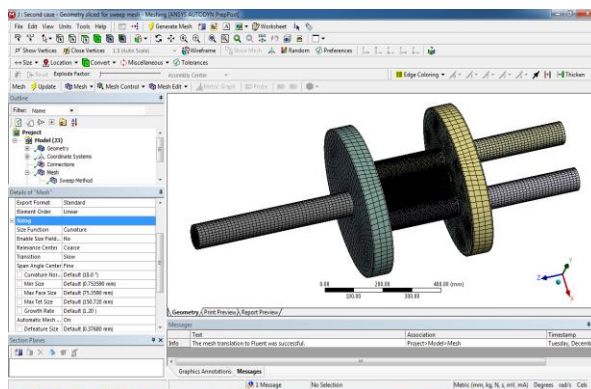


Figure 3 Mesh structure near perforated pipes

SIMULATION RESULTS:

REACTIVE MUFFLER:

CASE 1:

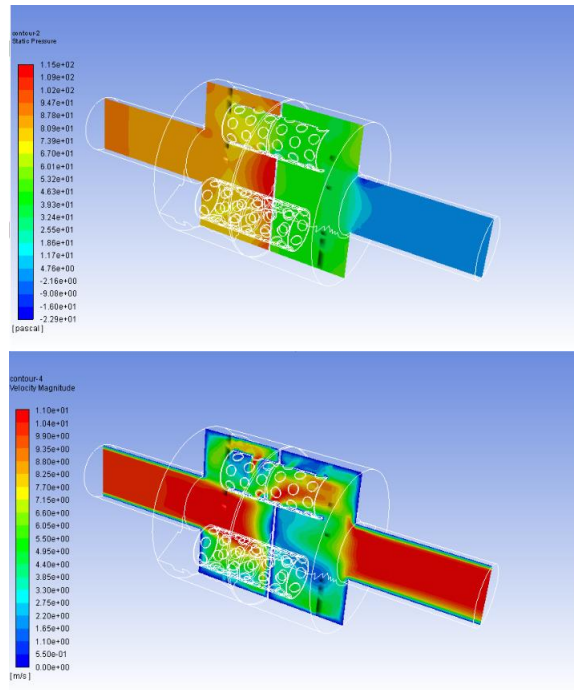


Figure 4 Pressure and velocity contours of reactive muffler case 1

CASE 2:

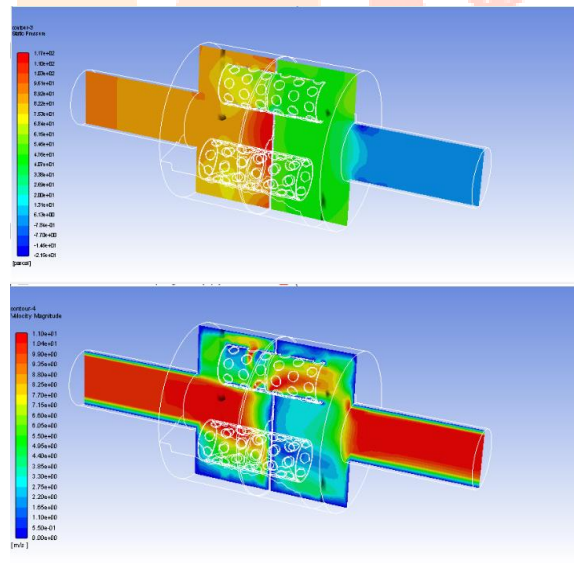
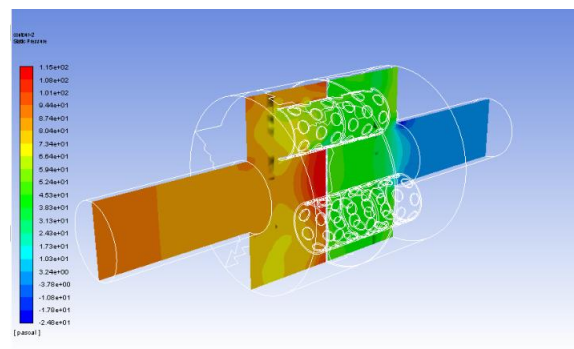


Figure 4 Pressure and velocity contours of reactive muffler case 2

CASE 3:



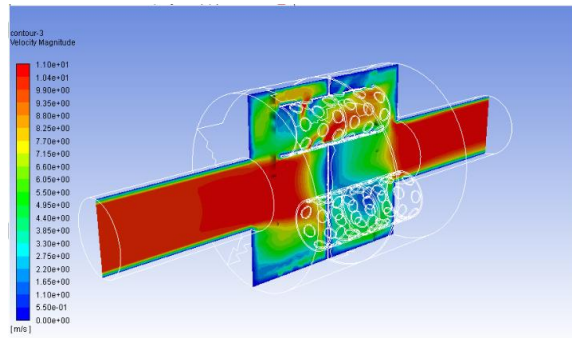


Figure 4 Pressure and velocity contours of reactive muffler case 3

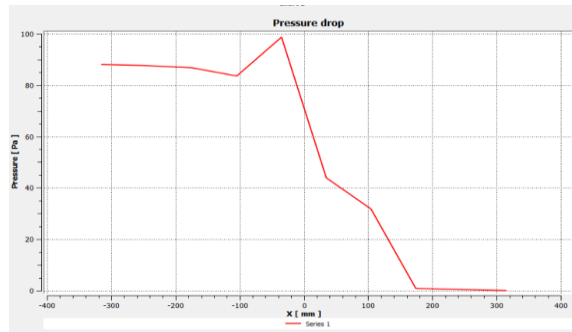


Figure 7.1 Variation of pressure with length for reactive case-1

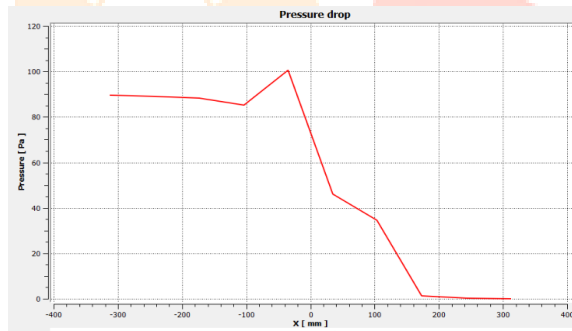


Figure 7.1 Variation of pressure with length for reactive case-2

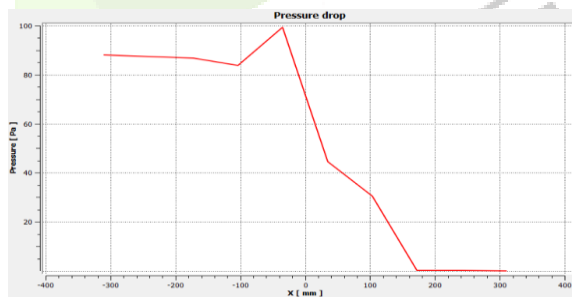
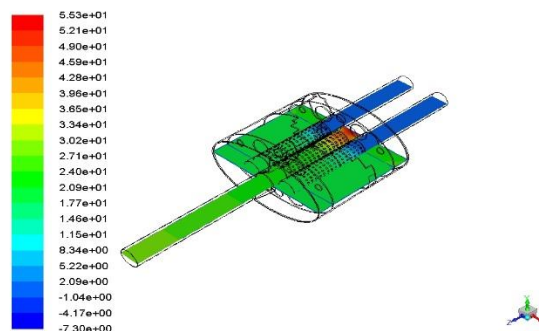


Figure 7.1 Variation of pressure with length for reactive case-3

**RESONATIVE MUFFLER:
CASE 1:**



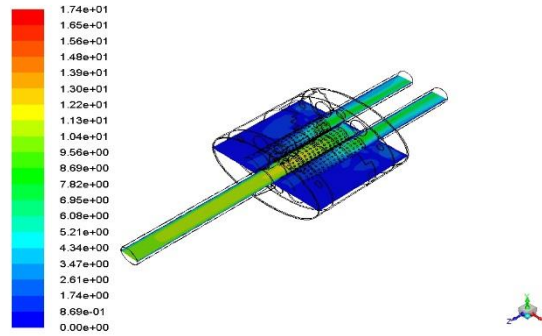


Figure 4 Pressure and velocity contours of resonative muffler case 1

CASE 2:

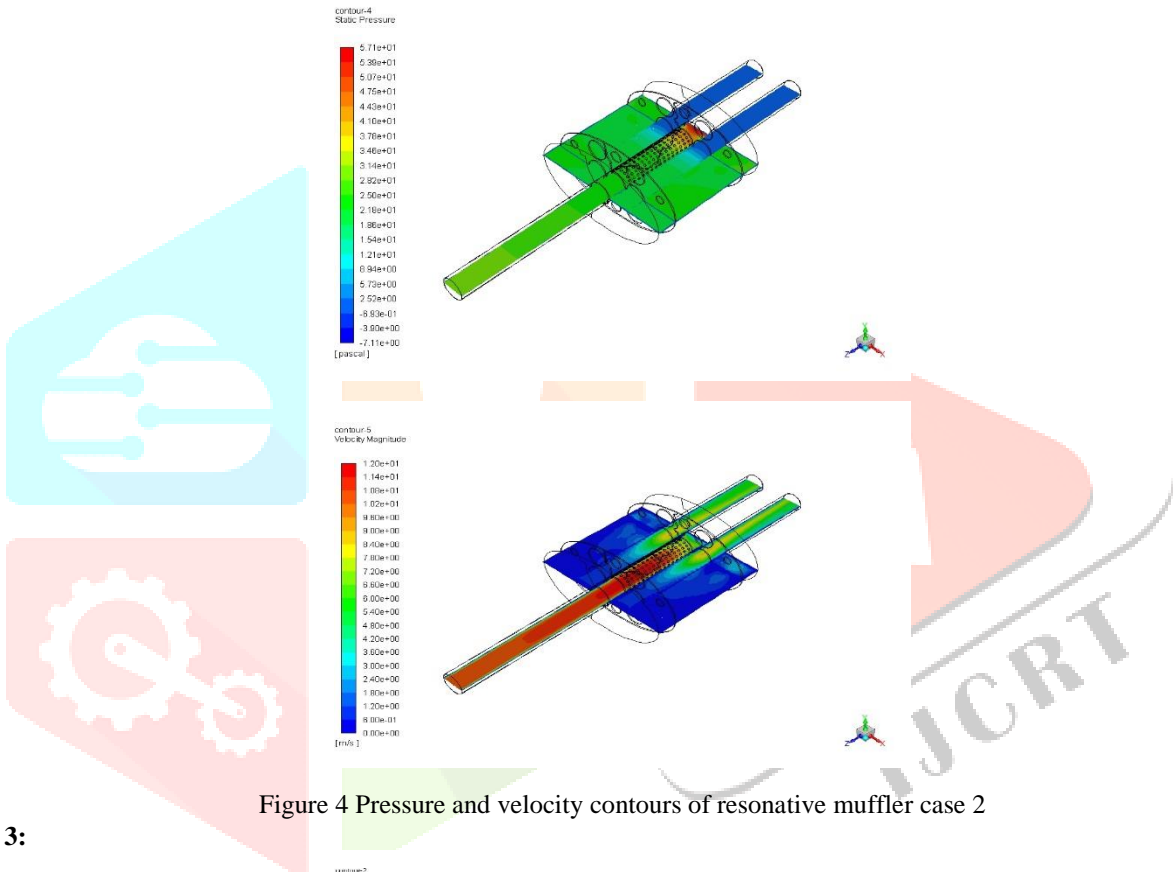


Figure 4 Pressure and velocity contours of resonative muffler case 2

CASE 3:

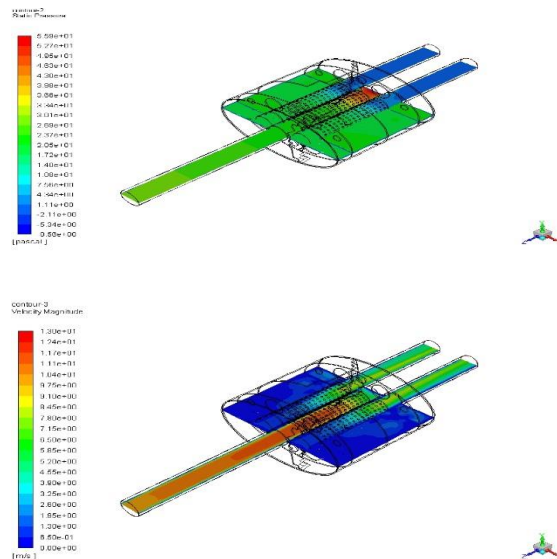


Figure 4 Pressure and velocity contours of resonative muffler case 3

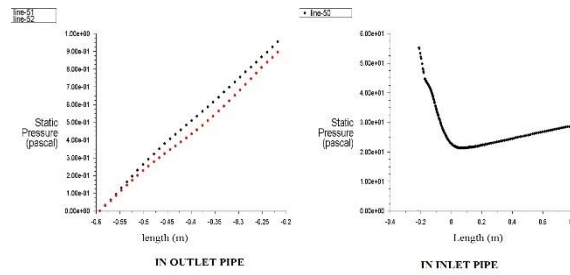


Figure 7.1 Variation of pressure with length for resonative case-1

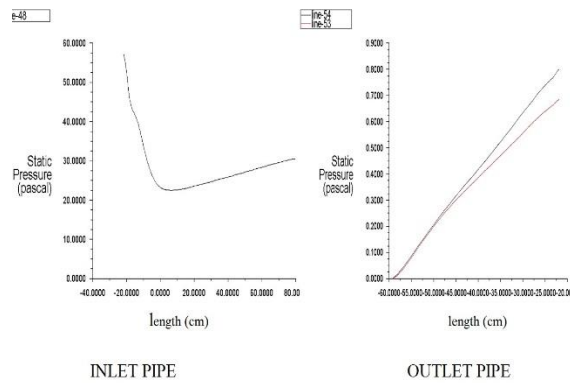


Figure 7.1 Variation of pressure with length for resonative case-2

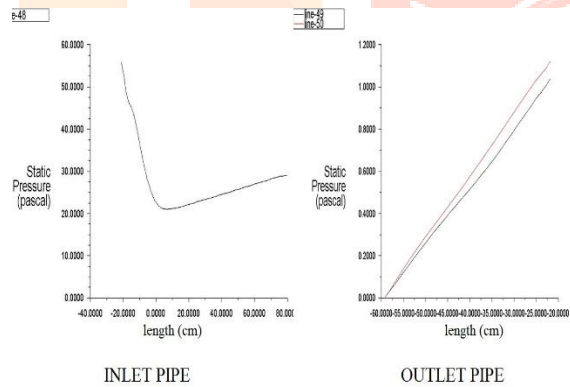
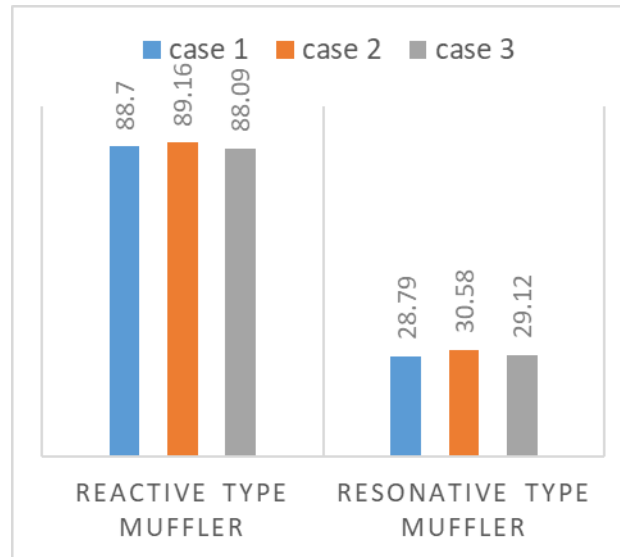


Figure 7.1 Variation of pressure with length for resonative case-3

CONCLUSION:

In present work, study of two different muffler designs has been carried out to choose the best design which can satisfy the flow conditions in an exhaust system. After carrying out analyses and studying the manufacturing feasibility of muffler designs, following conclusion are drawn.

- Below figure shows the total pressure drop occurring in different muffler designs.
- From this study it is concluded muffler case-3 in reactive muffler design and case-1 in resonative muffler design gives very low pressure drop.
- If results of all muffler design are compared, resonative muffler design case-1 is giving good results with low pressure drop.



FUTURE WORK:

The study presented here has its own advantages and disadvantages. In designs of the mufflers, focus has been put on the parameters like perforation with pipe and baffles; number of baffles and analyses has been carried out with fixed exhaust pipe. Though there is no change expected in the analyses if exhaust pipe which comes from engine is varied, this can be verified in future study. Also in perforation diameter which is maintained as 5 mm throughout the analyses. The effects of varying this diameter can also be studied; a higher diameter is expected to give better results.

REFERENCES:

- [1] Sudarshan Dilip Pangavhane , Amol Bhimrao Ubale , Vikram A Tandon , Dilip R Pangavhane, "Experimental and CFD Analysis of a Perforated Inner Pipe Muffler for the Prediction of Backpressure," .International Journal of Engineering and Technology (IJET)13-05-05-163
- [2] J.Kingston Barnabas, R.Ayyappan, M.R.Devaraj "Design and fabrication of exhaust silencer for construction equipment," Proceedings of the "National Conference on Emerging Trends In Mechanical Engineering 2k13"
- [3] P. S. Yadav, A. Muthukumar, V. V. Phani Kiran, V. Tandon and S. Raju,2007, "Optimized Design of Silencer -An Integrated Approach", SAE Paper No. 2007-26-037
- [4] M Mittal, R Donahue and P Winnie, "Evaluating the Influence of Exhaust Back Pressure on Performance and Characteristics of a Multicylinder, Turbocharged, and Aftercooled Diesel Engine", 2015,Journal of Energy Resources Technology Vol 137,May 2015.