Investigating the Effect on Transmission Loss of the Silencer Using Computational Fluid Dynamics Analysis

[1]Amit Kumar, [2]Shamir Daniel, [3]Jeetendra Mishra

[1]M.Tech Scholar, Department of Mechanical Engineering, Truba Institute of Engineering & Information Technology, Bhopal, MP, India.

[2]Assistant Supervisors, Department of Mechanical Engineering, Truba Institute of Engineering & Information Technology, Bhopal, MP, India.

[3]Assistant Supervisors, Department of Mechanical Engineering, Truba Institute of Engineering & Information Technology, Bhopal, MP, India.

Email [1]vgsamit@gmail.com, [2]shamirdaniel3004@gmail.com. [3]jeetendra.mishra@trubainstitute.ac.in

* Corresponding Author: Amit Kumar

Abstract: *This study investigates the role of mufflers in reducing vibrations and noise in vehicles to enhance riding comfort. Mufflers are integral components of the exhaust system in internal combustion engines, aimed at decreasing noise and back pressure while improving engine performance. Two main types of mufflers, absorptive and reactive, are examined, with a focus on their construction and operation. The study also explores the regulatory noise standards for vehicles in India and the methodology used to analyze muffler performance, including 3D modeling, meshing, and CFD analysis. Through mathematical formulations and FEM modeling, the transmission losses of three different muffler cases are evaluated and compared to identify the optimum design. It is observed that in Case 3(d=3 mm, D=36 mm, and L=300):), the best result for transmission losses was obtained from the proposed work,, with a value of 11.767 dB.*

Keywords: *Muffler, vibration reduction, noise reduction, transmission losses, exhaust system, CFD analysis, FEM modeling, noise standards, vehicle regulations, riding comfort*

I.INTRODUCTION

A muffler is used in vehicle as it plays a key role to reduce the vibration by increase the riding comfort. The muffler is arranged in exhaust framework after prescribed catalytic converter and furthermore end segment appended in waste gases framework. Mufflers are routed in exhaust system in internal combustion engines [1]. It is a device designed in such a way that it is used to reduce the vibration and to reduce the back pressure which in turn creates noise created by the engine. Each muffler is intended to lessen the commotion of any motor. This decrease in noise additionally lessens the back pressure created in the motor and improves the exhibition of the motor. The motor exhaust is associated through exhaust line to silencer called suppressor to control or diminish the exhaust commotion [2]. The deepness and immensity of the noise will fluctuate contingent on the sort of motor like normally aspirated or turbocharged, torque created, power produce, sort of fuel and number of cycles.

A. Automotive Parts and Systems can be organized into Ten Major Categories

- ✓ Body and frame- support and enclose the vehicle
- ✓ Engine- provides dependable, efficient power for the vehicle.
- ✓ Computer systems- monitor and control various vehicle systems.
- ✓ Fuel system- provides a combustible air-fuel mixture to power the engine.
- ✓ Electrical system- generates and/or distributes the power needed to operate the vehicle's electrical and electronic components.

B. Exhaust and Emission Control Systems

The exhaust system quiets the noise produced during engine operation and routes engine exhaust gases to the rear of the vehicle body. Trace the flow of exhaust gases from the engine exhaust manifold to the tailpipe Learn the names of the parts. Various emission control systems are used to reduce the amount of toxic (poisonous) substances produced by an engine. As shown in below figure 1.

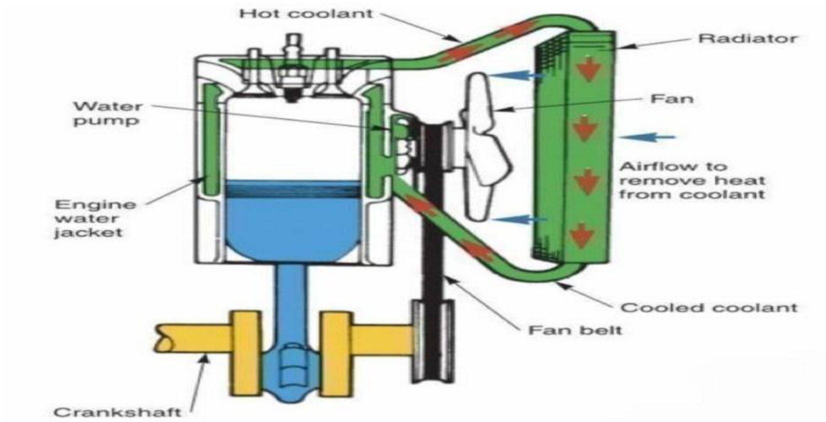

Figure.1 Exhausts and Emission Control System

C. Muffler Construction

The first muffler was patented in 1897 by Marshall and Milton Reeves. The muffler is the main component of the exhaust system for silencing acoustic exhaust noises. There are many different designs of mufflers available today. Some being chambered, glass pack, straight through glass packs and combinations of those. It is designed to reduce loudness acoustic back pressures created by the combustion process. Fiberglass is the most commonly used material inside of traditional mufflers. Other materials could include rock minerals, wool, fiber mat, or simple metal chambers to aid in absorption and reduce unwanted exhaust sounds [8].A muffler must be able to withstand the running conditions of a vehicle. This includes the engine sound frequencies, hazardous driving conditions (off- roading), and most of the muffler must withstand rust and corrosion [9]. As shown in below figure 2.

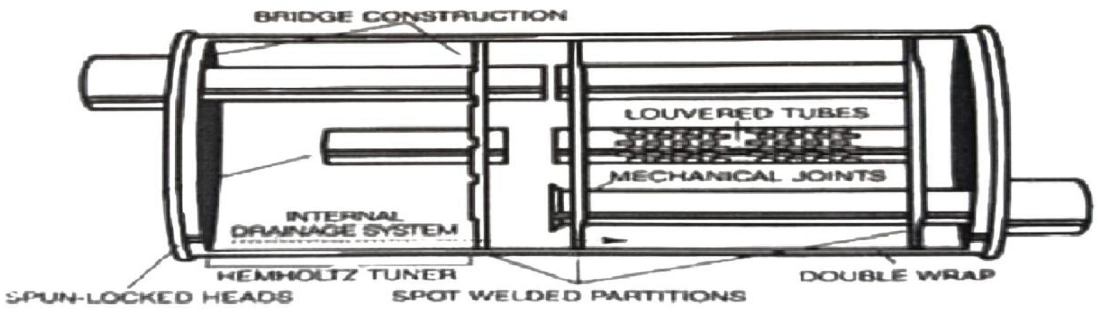

Figure 2 Sectional view of the muffler

D. Types of mufflers

There are generally 2 types of mufflers which are listed below

- Absorptive muffler
- Reactive muffler

E. Noise Standard in India

The central pollution control board constituted committee on noise pollution control. The committee recommended noise standards for ambient air and for automobiles according to various zones are as follows:

The Noise Limits for vehicles were notified by Environment (Protection) Amendment Rules, 2000. Noise limits for vehicles applicable at manufacturing stage applicable from 1st April, 2005 are as given in the table below 1.Respectively.

Table 1. Noise Standards in India

Area	Day time noise limit (dB)	Night time noise limit (dB)
Industrial area	75	70
Commercial area	65	55
Residential area	55	45
Silence zone	50	40

F. Working of Muffler

Mufflers are used mainly to dissipate the loud sounds created by the engine's pistons and valves. Every time your exhaust valve opens, a large burst of the burnt gases used during your engine's combustion is released into the exhaust system. This release of gases creates very powerful sound waves. To understand how a muffler dissipates the sound waves created by your engine, one must understand how sound is produced. Back is a pressure wave formed by vibrations. These vibrations are pulses of alternating high and low air pressure.

So, every time your exhaust valve opens, a very high-pressured gas enters into the exhaust system. These high-pressure gases will collide with low-pressure molecules, create pressure waves (sound), and travel through the exhaust system.

II.LITERATURE REVIEW

Palandeet. al. (2022) [1] "Comprehensive Review of Karanja and Jatropha Biodiesel Fuelled Diesel Engines" reduces the vibration and temperature of warm gases popping out of engine muffler are used as a completely crucial part of an exhaust device. So, it will become a necessary parameter to discharge these exhaust gases with minimum restrict to the environment. Even as discharging again strain is created so because of which it consumes extra fuel and decline within the efficiency of an engine is determined.

Kumar et al. (2021) [2] "Design and Analysis of a Muffler for Engine Exhaust Noise and Heat Reduction" carried out analyses and utilizing ANSYS workbench the steady state thermal analysis is done. Due to higher pollution levels India is undergoing tremendous changes in emissions norms, so the study and development of muffler is required.

Aware et. al. (2020) [3] "Optimization of Automobile Muffler Using Computational Fluid Dynamics" developed a CAD model of a laminar flow performance muffler, which consists of a converging-diverging duct. These ducts contain perforations on their walls through which the exhaust gases scatter after passing in different directions. The material of a muffler should be resistant to corrosion at high temperatures, salt corrosion resistance from the high-temperature exhaust gas, vibration resistance and at the same time it should also possess sufficient strength to withstand high stresses and also be light in weight and affordable at the same time.

Kulkarni and Ingle (2018) [4] "CFD-based biomass fast pyrolysis simulations in a gas-solid vortex reactor demonstrating process intensification" described the acoustic Analysis of Double Expansion Chamber Reactive (DEC) Muffler with various combinations of placement of side outlet. The approach is useful in the acoustic analysis of Double Expansion Chamber Muffler for maximizing Sound Transmission Loss. The purpose of paper is to study the effect of placement of side outlet on transmission loss of Double Expansion Chamber Reactive Muffler with the help of numerical analysis using COMSOL Multiphysics.

Zhao et al. (2015) [5]"Comparison of indoor aerosol particle concentration and deposition in different ventilated rooms by numerical method"designed compressor inlet muffler by using the FEM and calculated the transmission loss. And the feasibility of finite element analysis was verified by experiments. Based on the FEM, Krynkin21 combined ANSYS with MATLAB to improve the structure of the muffler and got better performance of the muffler.

Guhan et al. (2018) [6] "Exhaust system muffler volume optimization of light commercial vehicle using CFD simulation "mitigated the weight of existing exhaust systems by optimizing the muffler volume with the 3D design tool CATIA V5 and the computational fluid dynamics commercial tool ANSYS CFX. Existing mufflers were analyzed and physical tests were performed at the vehicle level. Physical test results showed that optimizing the structural parameters of the muffler not only enables the muffler to have better performance but also provided cost-effective and fuel economy advantages.

III. OBJECTIVES

The following objectives are covered in this study:
To analysis the performance of muffler and examine the effect of performance parameters on the transmission losses.
Optimum the parameter towards maximum transmission losses. validate the results associated with the optimum parameter for maximum transmission losses

IV. RESEARCH METHODOLOGY

A. Methodology adopted

Research methodology regarding the static analysis and design optimization of muffler is accomplished in four steps which are as follows:

- Design of muffler
- 3D modelling of muffler
- Meshing of muffler
- Applying boundary conditions for CFD analysis

- Results
- Optimum parameters
- Optimum design

B. Mathematical Formulation

- Transmission loss is defined as the ratio of the incident power and transmitted power from the structure. Symbolically,
- $\mathrm{TL} = 10\ \mathrm{Log}_{10}\left(\frac{S_i P_i^2}{S_O P_O^2}\right)\mathrm{dB}$ (1)
- where S_i and S_o are the cross-sectional areas of the inlet and outlet of the muffler. Pi and Po are the acoustic pressure of the incident wave at the inlet of the muffler and transmitted wave at the outlet of the muffler respectively.
- The aforementioned formula can be stated in modified form as follows in the present case where the muffler's inlet and outlet have equal cross-sectional areas:
- $\mathrm{TL} = 20\ \mathrm{Log}_{10}\left(\frac{P_i}{P_O}\right)\mathrm{dB}$ (2)

C. FEM Modelling Of Muffler

FEM is an approximation approach at its most simplistic form that divides a complex problem space or domain into several smaller and simpler parts (finite elements), which can be represented in relatively simple equations. FEM has been designed for the engineering study of electronic, civil and aeronautical engineering structures to model and analysis complex. It has the fundamental principles of physics, such as Newton's laws of movement, mass preservation, energy conservation, balancing, and thermodynamics laws. The FEM may be used to evaluate for example the structural dynamics of the various sections of a bridge, heat transfer through a motor component, or the dispensing of the electromagnetic radiation from an antenna under different loading conditions. The subdivision of the domain is an essential feature of FEM. Computer-aided program (CAD) is helpful in this respect since it determines an object's three-dimensional form, conveniently split up to the desired net or three-dimensional grid of items of the required sizes. The mesh can describe elements of the same size and shape (such as cubes or pyramids) in different shapes or sizes in different sections of the domain, depending on the problem to be solved. The proper mesh or element model must be chosen: The results with a coarser mesh (larger subdivisions), but a smaller mesh that generates more components that demand more processing resources to solve. The outcomes are less precise. So it's useful to provide a mesh that varies across the domain.

D. 3D Modelling Of Muffler

ANSYS can also be used for the 3D solid modelling of muffler that enables users to create comprehensive, models of design and analysis in a virtual environment. ANSYS build 3D models by drawing concepts and experimenting with various designs using design modeller module. ANSYS produces basic 3D model for designers, engineers and other practitioners. It is useful to develop a simulation model such as Solid Works, and therefore it saves time, effort and resources to develop the design. Table 2 shows the dimensions and variations across variables that are used to create 3D models of muffler. After creating CAD model of muffler, it is imported in meshing module for CFD analysis. As given in the table below 2 & 3 respectively

Table 2 Parameters for simulation

Case 1	d= 2.33 mm, D=36 mm and L=300 mm
Case 2	d=2 mm, D=36 mm and L=300 mm
Case 3	d=3 mm, D=36 mm and L=300 mm

Table 3 Geometrical dimensions of muffler case 1

Hole diameter (mm)	2.33
Tube diameter (mm)	36
Tube length (mm)	300
Hole spacing (mm)	4
Muffler diameter (mm)	160

E. Boundary Conditions

Another important phase in the study after the meshing method is the applied boundary condition in such a way that meets the real-life circumstances. The applied boundary conditions are applied on muffler as shown in Fig. 3.Boundary condition has been adopted from the study of. As shown in below figure 3

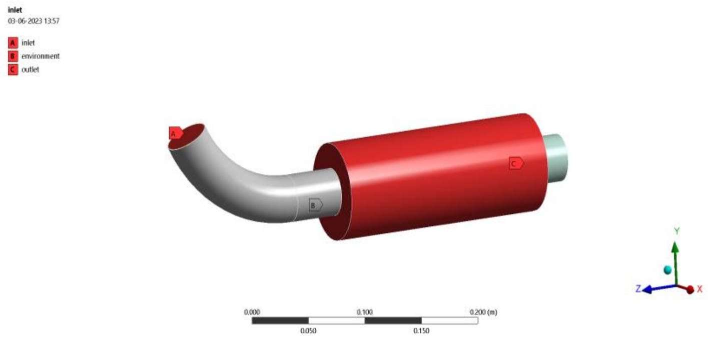

Figure3 Boundary condition applied

V. RESULTS AND DISCUSSION

In this study three case were formulated and transmission losses are evaluated. In case 1, this study used same optimum parameter which was found from the study of Kashikar et al. (2021), as d=2.33 mm, D=36 mm and L=300 mm and transmission loss (TL) at this optimum parameter was found as 10.572 dB. In case 2, d is taken as 2 mm and in case 3, d is taken as 3 mm with same D and L. All three cases are simulated using CFD and compared based on TL with base paper.

A. Transmission Losses For Case 1 (d=2.33 mm, D=36 mm and L=300)

The pressure distribution. that the pressure of exhaust gas is higher at muffler entrance pipe and gradually decreases at outlet.

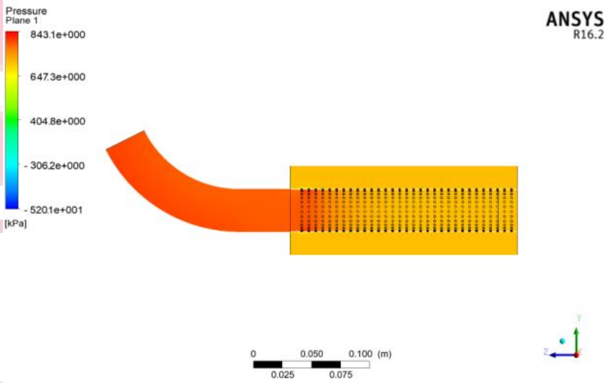

Figure 4 Pressure contour for case 1

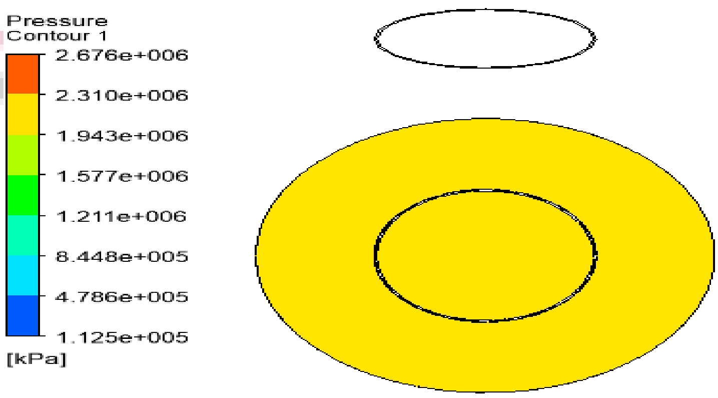

Figure 5 Pressure contour at outlet for case 1

When exhaust gases enter the muffler through the entrance pipe, they contain high-pressure energy due to the combustion process in the engine. As the high-pressure exhaust gas enters the muffler, it encounters perforated holes. These holes are strategically designed to create resistance and introduce changes in direction to the flow of gases.The changes in direction and the presence of obstacles inside the muffler cause a phenomenon called pressure drop or pressure loss.As the exhaust gases navigate through the perforated holes inside the muffler, the pressure gradually decreases. The combination of the resistance from the muffler's internal components and the sound-absorbing materials causes a gradual reduction in pressure as the gases move towards the outlet. As given in the below table 4.

Table 4: Summary of pressure results

Case	Inlet pressure (pi)	Out pressure (Po)
1	843.10	267.56

The velocity contour of a muffler refers to the distribution and variation of gas velocity within the muffler. It provides a visual representation of how the gas velocity changes as it passes through the perforated holes in the muffler.

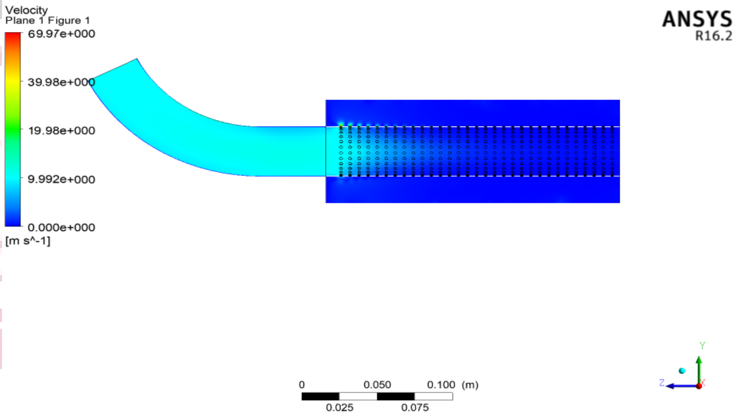

Figure 6 Velocity contour for case 1

The gas velocity is initially high at the en trance pipe of the muffler. This is because the exhaust gases are being expelled from the engine and enter the muffler with considerable momentum. The gas velocity decreases as the exhaust gases enter the perforated holes of the muffler. An expansion chamber is designed to increase the volume available for the gases, which causes a reduction in velocity.

The temperature contour of a muffler refers to the distribution and variation of gas temperature within the muffler. It provides a visual representation of how the gas temperature changes as it passes through the different components and chambers of the muffler. The gas temperature is initially high at the entrance pipe of the muffler. This is because the exhaust gases are hot and come directly from the engine combustion process.

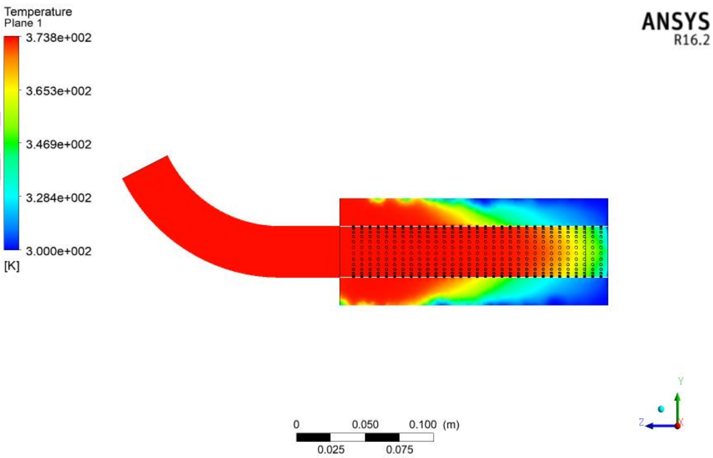

Figure 7 Temperature contour for case 1

B. Transmission Losses For Case 2 (d=2 mm, D=36 mm and L=300)

The pressure distribution. As can be seen from that the pressure of exhaust gas is higher at muffler entrance pipe and gradually decreases at outlet. When exhaust gases enter the muffler through the entrance pipe, they contain high-pressure energy due to the combustion process in the engine. As the high-pressure exhaust gas enters the muffler, it encounters perforated holes. These holes are strategically designed to create resistance and introduce changes in direction to the flow of gases.The changes in direction and the presence of obstacles inside the muffler cause a phenomenon called pressure drop or pressure loss. The pressure drop occurs because the flow of gases encounters resistance, leading to a decrease in pressure. Additionally, the sound-absorbing materials in the muffler also contribute to the pressure drop. As the exhaust gases navigate through the perforated holes inside the muffler, the pressure gradually decreases. The combination of the resistance from the muffler's internal components and the sound-absorbing materials causes a gradual reduction in pressure as the gases move towards the outle

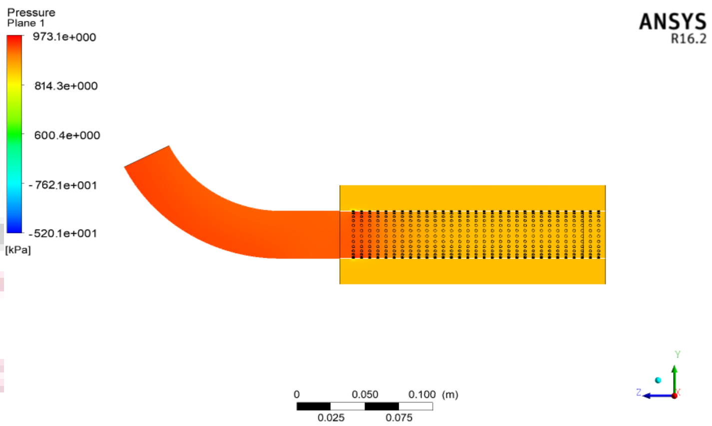

Figure 8 Pressure contour for case 2

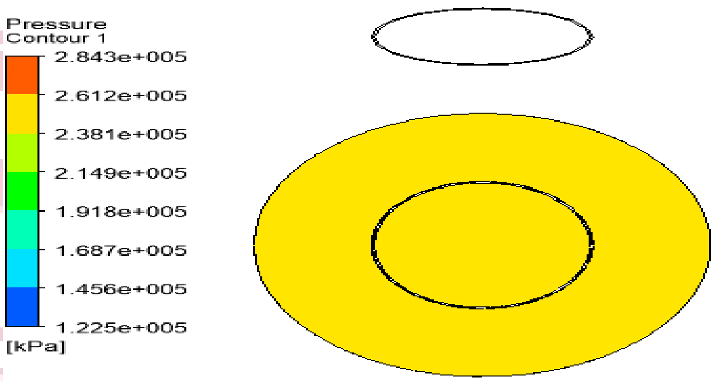

Figure 9 Pressure contour at outlet for case 2

As the exhaust gases navigate through the perforated holes inside the muffler, the pressure gradually decreases. The combination of the resistance from the muffler's internal components and the sound-absorbing materials causes a gradual reduction in pressure as the gases move towards the outlet As given in the below table 5.

Table 5 Summary of pressure results

Case	Inlet pressure (pi)	Out pressure (Po)
2	973.1 k.pa	284.31 k.pa

The velocity contour of a muffler refers to the distribution and variation of gas velocity within the muffler. It provides a visual representation of how the gas velocity changes as it passes through the perforated holes in the muffler. The gas velocity is initially high at the entrance pipe of the muffler. This is because the exhaust gases are being expelled from the engine and enter the muffler with considerable momentum.In a typical muffler, the gas velocity contour is not uniform throughout the entire system. It varies based on the design of the muffler and the specific components it incorporates.

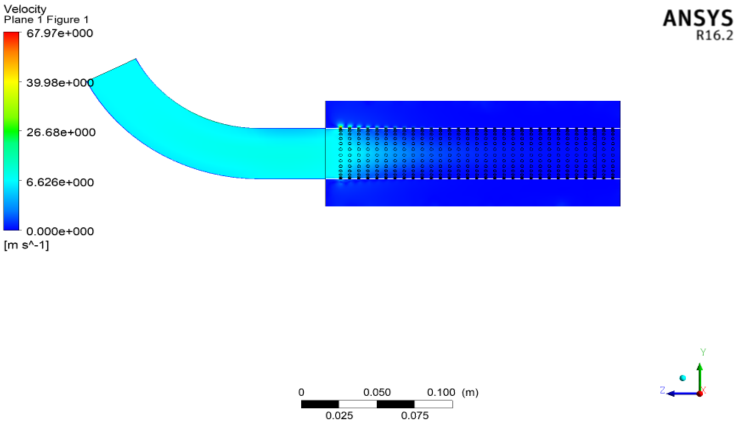

Figure 10 Velocity contour for case 2

The temperature contour of a muffler refers to the distribution and variation of gas temperature within the muffler. It provides a visual representation of how the gas temperature changes as it passes through the different components and chambers of the muffler. The gas temperature is initially high at the entrance pipe of the muffler. This is because the exhaust gases are hot and come directly from the engine combustion process. The presence of perforated tubes or pipes in some mufflers can impact the gas temperature

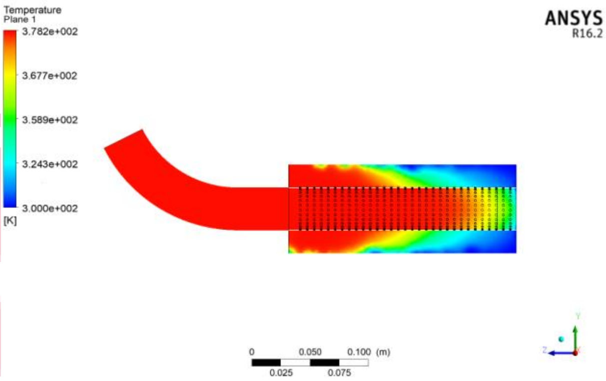

Figure 11 Temperature contour for case 2

C. Transmission Losses for Case 3 (d=3 mm, D=36 mm and L=300)

The pressure of exhaust gas is higher at muffler entrance pipe and gradually decreases at outlet. When exhaust gases enter the muffler through the entrance pipe, they contain high-pressure energy due to the combustion process in the engine.

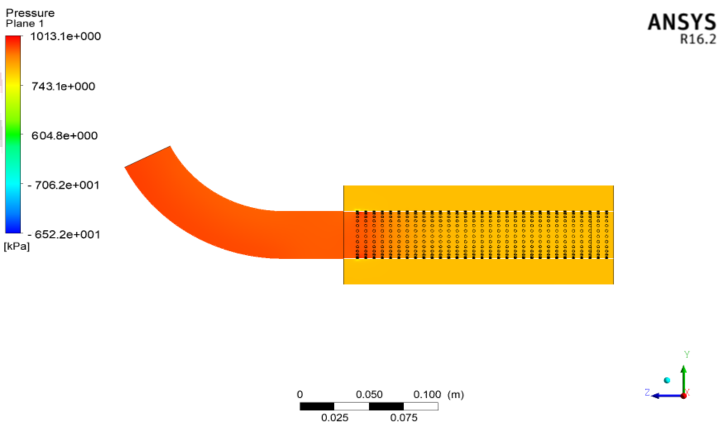

Figure 12 Pressure contour for case 3

As the high-pressure exhaust gas enters the muffler, it encounters perforated holes. These holes are strategically designed to create resistance and introduce changes in direction to the flow of gases. The changes in direction and the presence of obstacles inside the muffler cause a phenomenon called pressure drop or pressure loss. The pressure drop occurs because the flow of gases encounters resistance, leading to a decrease in pressure. Additionally, the sound-absorbing materials in the muffler also contribute to the pressure drop. As the exhaust gases navigate through the perforated holes inside the muffler, the pressure gradually decreases. The combination of the resistance from the muffler's internal components and the sound-absorbing materials causes a gradual reduction in pressure as the gases move towards the outlet

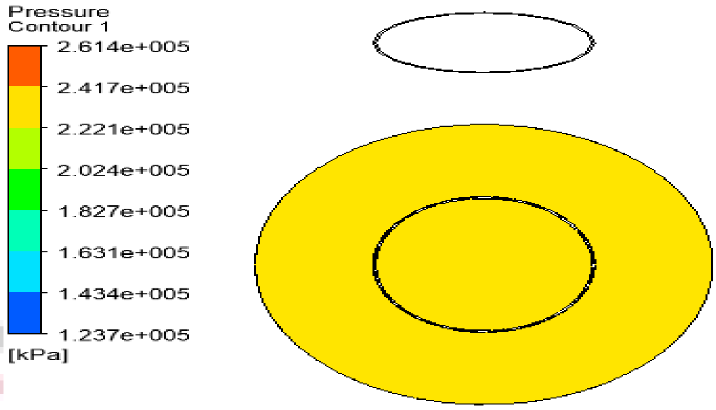

Figure 13 Pressure contour at outlet for case 3

As the exhaust gases navigate through the perforated holes inside the muffler, the pressure gradually decreases. The combination of the resistance from the muffler's internal components and the sound-absorbing materials causes a gradual reduction in pressure as the gases move towards the outlet as given in the below table 6.

Table 6 Summary of pressure results

Case	Inlet pressure (pi)	Out pressure (Po)
3	1013.1 k.pa	261.39 k.pa

The velocity y contour of a muffler refers to the distribution and variation of gas velocity within the muffler. It provides a visual representation of how the gas velocity changes as it passes through the perforated holes in the muffler. The gas velocity is initially high at the entrance pipe of the muffler. This is because the exhaust gases are being expelled from the engine and enter the muffler with considerable momentum.

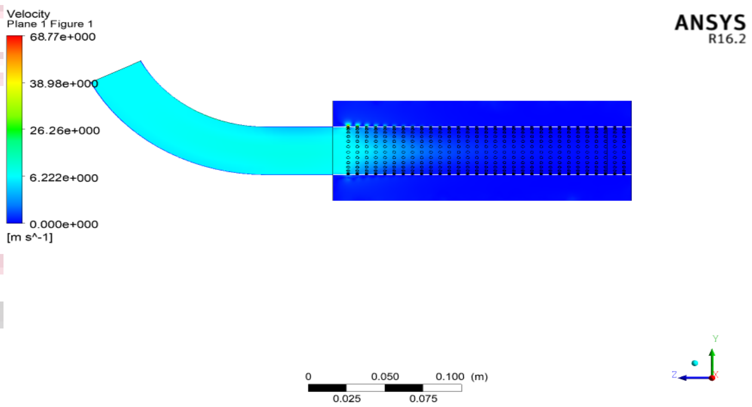

Figure 14 Velocity contour for case 3

The temperature contour of a muffler refers to the distribution and variation of gas temperature within the muffler. It provides a visual representation of how the gas temperature changes as it passes through the different components and chambers of the muffler (see fig. 5.12). The gas temperature is initially high at the entrance pipe of the muffler. This is because the exhaust gases are hot and come directly from the engine combustion process. The presence of perforated tubes or pipes in some mufflers can impact the gas temperature.

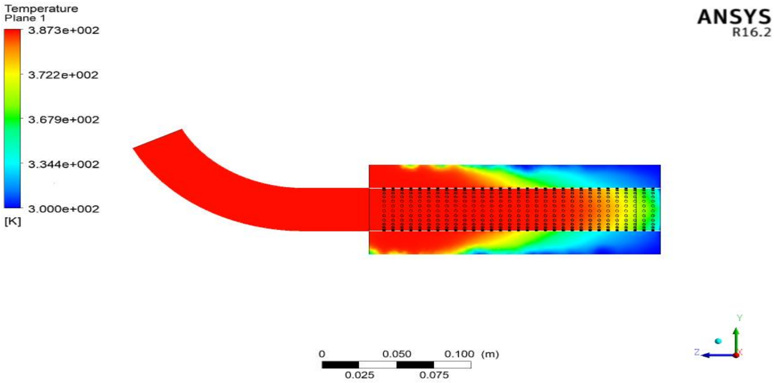

Figure 15 Temperature contour for case 3

Table 7 Summary of results

S.N	Transmission losses (TL) (dB) from present study	Transmission losses (TL) (dB) from the study of Kashikar et al. (2021)
Case 1(d=2.33 mm, D=36 mm and L=300)	9.969	10.572
Case 2(d=2 mm, D=36 mm and L=300)	10.687	
Case 3(d=3 mm, D=36 mm and L=300)	11.767	

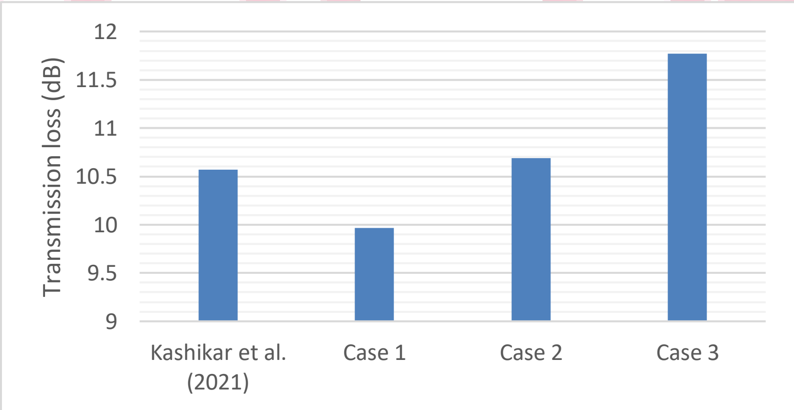

Figure 16 Variation of transmission loss

The graph compares transmission losses (TL) in dB from the present study with a previous study by Kashikar et al. (2021). In Case 1, the present study achieved better results (9.969 dB) compared to Kashikar et al. (10.572 dB). Case 2 and Case 3 results are only available from the present study (10.687 dB and 11.767 dB, respectively).

V.CONCLUSION

Mufflers play a vital role in reducing vibrations and noise in vehicles, leading to enhanced riding comfort. This study demonstrates the significance of mufflers in the exhaust system of internal combustion engines, where they effectively decrease noise and back pressure, consequently improving engine performance. The research explores two primary types of mufflers, absorptive and reactive, shedding light on their construction and functioning. The study also highlights the importance of adhering to noise standards for vehicles, as established by regulatory bodies in India. Using advanced methodologies, such as 3D modeling, meshing, and CFD analysis, the study evaluates the performance of different muffler designs. The investigation of transmission losses in three distinct muffler cases provides valuable insights into the impact of hole diameter on noise reduction. The results obtained from the FEM modeling further validate the effectiveness of the optimized muffler design.

Overall, this study contributes to the understanding of muffler technology and its role in noise reduction and engine performance enhancement. It provides valuable information for engineers and researchers to optimize muffler designs and comply with noise regulations to create more comfortable and environmentally friendly vehicles.

REFERENCES

[1] Palande, D &Ghuge, Nilesh&Shrivastwa, Rakesh&Shriwastava, Rakesh. (2022). Comprehensive Review OfKaranja And Jatropha Biodiesel Fuelled Diesel Engines. Transdisciplinary Journal of Engineering & Science. SP-2. 85-96. 10.22545/2022/00201.

[2] Kumar, S. D., Praveenkumar, N., Arulkumar, S., Boopalan, N., (2021). Design and Analysis of a Muffler for Engine Exhaust Noise and Heat Reduction. 2021-28-0128. SAE Technical Paper.

[3] Aware, MrMayur Shankar. (2020) Optimization Of Automobile Muffler Using Computational Fluid Dynamics. International Journal Of Advance Scientific Research And Engineering Trends, 4 , 5, 2019-2020,2456-0774 .

[4] Kulkarni, S. R., Gonzalez-Quiroga, A., Perreault, P., Sewani, H., Heynderickx, G. J., Van Geem, K. M., & Marin, G. B. (2018). CFD-based biomass fast pyrolysis simulations in a gas-solid vortex reactor demonstrating process intensification. Chemical Engineering Transactions, 65, 19-24.

[5] Zhao B, Zhang Y, Li X, Yang X, Huang D (2015). Comparison of indoor aerosol particle concentration and deposition in different ventilated rooms by numerical method. Building and Environment, 39: 1–8.

[6] Guhan, C. O. A., Arthanareeswaran, G., Varadarajan, K. N., & Krishnan, S. (2018). Exhaust system muffler volume optimization of light commercial vehicle using CFD simulation. Materials Today: Proceedings, 5(2), 8471-8479.

[7] Fang, H., Li, K., Wu, G., Cheng, R., Zhang, Y., & Yang, Q. (2017). A CFD analysis on improving lettuce canopy airflow distribution in a plant factory considering the crop resistance and LEDs heat dissipation. Biosystems Engineering, 200, 1-12

[8] Yasuda, T., Wu, C., Nakagawa, N., &Nagamura, K. (2010). Predictions and experimental studies of the tail pipe noise of an automotive muffler using a one dimensional CFD model. Applied Acoustics, 71(8), 701-707.

[9] Guhan, C. O. A., Arthanareeswaran, G., Varadarajan, K. N., & Krishnan, S. (2018). Exhaust system muffler volume optimization of light commercial vehicle using CFD simulation. Materials Today: Proceedings, 5(2), 8471-8479.

[10] Kashikar, A., Suryawanshi, R., Sonone, N., Thorat, R., & Savant, S. (2021). Development of muffler design and its validation. Applied Acoustics, 180, 108132.

inprotected.com