Atomic Spectroscopy

Article

Optimal Determination of Transmission Losses for Hybrid Absorptive Mufflers under Space Constraints using Different Absorptive Materials

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ABSTRACT: In this research work, a muffler has been designed using the finite volume method, and the results have been proven by making an experimental setup to validate its design. After this, in the research work, a muffler of the same dimension was designed using the finite volume method and by making changes in its design, like installing a baffle and making perforations in its pipe based on different flow percentages, and finally, the optimum muffler design was found. The last enhancement in sound transmission loss was seen by filling different sound-absorbing materials inside the muffler design at different densities.
Keywords: Hybrid Absorptive Muffler, Transmission Losses, Noise Reduction, Acoustics, Finite Element Analysis.

INTRODUCTION

Enhancing the entire auditory experience for people inside vehicles is a major goal in the modern automobile industry. It's crucial to find a balance so that person sitting inside can hear what they need to hear while minimizing outside noise. The car's muffler is one important element responsible for establishing this equilibrium. A muffler's main purpose is to minimize the amount of sound that is emitted. Effectively reducing noise pollution caused by vehicle noises is made feasible by carefully studying and making particular design improvements to the silencer. The muffler works by increasing the loss of sound transmission.

The ability of the silencer to attenuate sound waves produced by the engine and exhaust system, so reducing the overall noise released by the vehicle, is referred to as acoustic STL. The application of various acoustic engineering strategies, such as the use of acoustic materials, intricate interior chamber designs, and creative exhaust path arrangements, allows for the realization of this theory.

The primary goal of muffler design optimization is to lessen the strength and volume of sound waves that are delivered to the surrounding area. This aids in reducing noise pollution, resulting in a quieter and more relaxing environment for both the people within the vehicles and the broader public.

Additionally, improvements in muffler design technology have sparked the creation of specialized designs that focus on particular noise frequencies, such high-pitched exhaust noise or low-frequency rumble. In this work the muffler's design parameters weremodified properly attenuate these particular frequencies, enhancing the overall sound quality and lowering noise pollution.

In conclusion, the automobile sector understands the value of giving vehicle occupants a comfortable auditory experience while minimizing noise disruptions for others. The goal of this work is to lessen noise pollution caused by vehicle noises by paying close attention to muffler design and enhancing STL. These developments make driving safer, more fun, and more environmentally friendly for everyone.

The objective of this research is to design and develop hybrid absorptive mufflers by incorporating different types of absorptive materials, perforated tubes, and various chamber configurations. Experimental testing will be conducted to assess the mufflers' performance, with a primary focus on reducing transmission losses. This study aims to evaluate the effectiveness of hybrid mufflers compared to other muffler types by investigating the performance of different sound absorption materials through experimental validation.As hybrid absorptive mufflers have received limited attention compared to other muffler designs, this research aims to fill the knowledge gap by exploring their potential applications in both industrial and automotive settings. A hybrid muffler will be developed using wave 1-D analysis and its performance will be experimentally validated in a dedicated laboratory. Following experimental validation, single-baffle and double-baffle mufflers was constructed, incorporating sound absorptive materials.Through experimental validation and comparison, mainaim is to determine the optimal design configurations that offer improved noise reduction capabilities. The findings of this study will add the advancement of hybrid muffler technology and provide insights for future design optimizations in noise control applications.

Effects of Loud Noise

Our physical health and psychological well-being can both be significantly impacted by noise exposure. Loud noises can have both direct and indirect consequences on our health, including the possibility of damaging our hearing. The possibility of hearing loss brought on by protracted exposure to loud noises is one immediate cause for concern. Continuously being around loud noises, especially without the correct hearing protection, might harm the sensitive inner ear components permanently. This can cause a variety of hearing losses over time, from minor to severe. It's crucial to be aware of the possible effects of excessive noise on our hearing because the damage may develop gradually and softly, frequently going unnoticed in its early stages [1].

Moreover, excessive noise in the workplace can have broader implications for overall health. Occupational noise, especially when experienced over long durations, has been linked to various health issues beyond hearing loss. Prolonged exposure to loud noises in the work environment can contribute to stress, increased blood pressure, and cardiovascular problems. It can also disrupt sleep patterns, leading to fatigue and reduced cognitive performance. Additionally, noise-related stress can have psychological effects, including irritability, decreased concentration, and even health concerns.

Recognizing the potential impact of noise on our health and taking proactive steps to minimize exposure is vital. By prioritizing hearing conservation and implementing appropriate noise reduction strategies, we can safeguard our hearing health, reduce the risk of occupational health issues, and promote overall well-being[2].

Numerous organs and systems have altered functions as a result of noise exposure. Acute noise exposure can increase blood pressure, heart rate, and cardiac output in both lab settings simulating traffic noise and in actual surroundings. This effect is probably mediated by the production of stress hormones such catecholamines [3].

The organization of the brain's functional networks, particularly those involved in cognitive processing, is influenced by sensory experiences, which in turn have an impact on the structure and function of the brain. In this study, the author looked at how early deafness affects the structure of the brain's resting-state networks and how it relates to executive function.[4].

Various Applications of High-Level Noise

Appliance noise in homes can disturb peace and have a negative impact on wellbeing. Noise management is given top priority by manufacturers of household appliances. Improvements in motor and compressor technology, noise-absorbing materials, and vibration isolation all contribute to lower noise levels and quieter operation in household settings.[5].

Due to its possible health risks and negative effects on the environment, industrial noise presents considerable issues. Industrial establishments use a variety of noise control techniques to protect the health of their employees and the communities around them. These include installing sound barriers, enclosures, and mufflers on machinery as well as implementing engineering controls including isolation from vibrations, upkeep of equipment, and appropriate insulation. Additionally, personnel exposed to excessive noise levels are given personal safety equipment like earplugs and earmuffs.[6].

Aside from the obvious places like homes, offices, and autos where noise control is crucial, there are other uses that should also be considered. Environments where noise control is essential include public areas, healthcare facilities, educational institutions, and entertainment venues. In these circumstances, strategies including soundproofing materials, active noise cancellation devices, and architectural design considerations help to create relaxing and pleasing acoustics.[7].

HYBRID ABSORPTIVE MUFFLER FOR ACOUSTIC NOISE CONTROL

Theoretical Elements for Hybrid Absorbent Mufflers

In order to reduce noise, hybrid absorptive mufflers combine absorption and reflection techniques. When sound waves travel through materials that absorb sound, their energy is transformed into heat as a result of internal friction. On the other hand, reflection entails sound waves hitting solid objects and going through phase alterations to cancel out or diminish their amplitude.[8].

Design Criterion of Hybrid Absorptive Muffler

The acoustic behavior of hybrid absorptive mufflers can understand by modelling them using the Finite Element Method (FEM), which also makes it easier to optimize their design for efficient noise reduction. In order to anticipate acoustic performance and direct the creation of effective muffler designs, this work examines the principles and factors involved in the FEM modelling of hybrid absorptive mufflers.[9].

I.Meshing and Geometry:

Accurately representing the hybrid absorptive muffler's geometry is the initial stage in FEM modelling. This entails describing the muffler's interior and external surfaces, as well as any resonators, expansion chambers, baffles, or sound-absorbing components that may be present. Following that, the geometry is mesh-discretized into small elements to ensure a proper balance between accuracy and computing efficiency.[10].

II. Sound Absorbing Material Characteristics:

For effective FEM simulations, it is essential to assign precise acoustic material attributes. Hybrid absorptive mufflers' sound-absorbing components frequently display complicated behaviors, such as porosity, flow resistance, and tortuosity. To gather precise data for modelling, these properties are experimentally characterized using techniques like impedance tube testing. To simulate the acoustic behavior of the muffler, these material attributes are included to the FEM model.[11].

III.Conditions for Acoustic:

For the operational environment of the muffler to be properly represented, appropriate boundary conditions must be defined. For instance, the inlet and exit conditions must take into account the incoming flow and the local acoustic impedance. Depending on the particular scenario, one can use open, closed, or impedance boundary conditions. These boundary constraints make sure that the FEM model accurately depicts how the muffler interacts with its environment in terms of sound.[12].

IV. FEM Analysis:

The FEM model is solved using the necessary numerical solvers once the geometry, mesh, material parameters, and boundary conditions have been established. The sound pressure and particle velocity distributions inside the silencer are commonly determined by iteratively solving the acoustic wave equation, such as the Helmholtz equation. For acoustic simulations, FEM software systems like COMSOL, ANSYS, or ABAQUS offer specialized modules.[13].

V. Optimization and Validation:

By contrasting the FEM model's predictions with experimental data from real prototypes, its accuracy is confirmed. Model assumptions or material attributes can be improved based on discrepancies between the model and experimental findings. In order to achieve improved noise reduction performance, the verified FEM model can subsequently be used for optimisation studies to investigate different design factors, such as resonator diameters, material combinations, or internal gurgling.

METHODICAL APPROACH

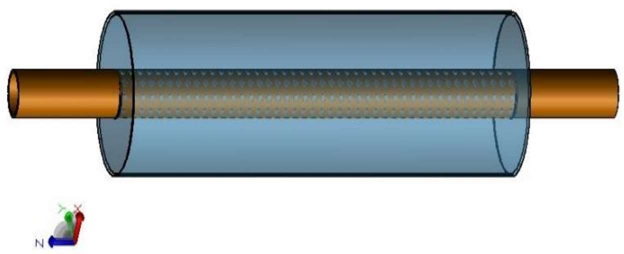

Figure 1: Model view of perforated muffler

In the present work, a blank muffler was fabricated and the STL was determined by wave analysis which come out to be 12.5 dB. After this, a perforated pipe was inserted in the muffler and the transmission loss increased to 14.8 dB when holes were made in 10% of the surface flow volume considering the total surface volume of the pipe. Similarly, when holes were made in 12.5 surface flow area, the STLcame to 16.1 dB and similarly on 15%

surface area, the STLwas 17 dB, which was the highest ever, after that, when holes were made in 17.5 surface flow area, the STLwas 15dB which was less than the previous one, thus the optimum design with perforated pipe was found with 15% surface flow area as indicated in below graph 2.

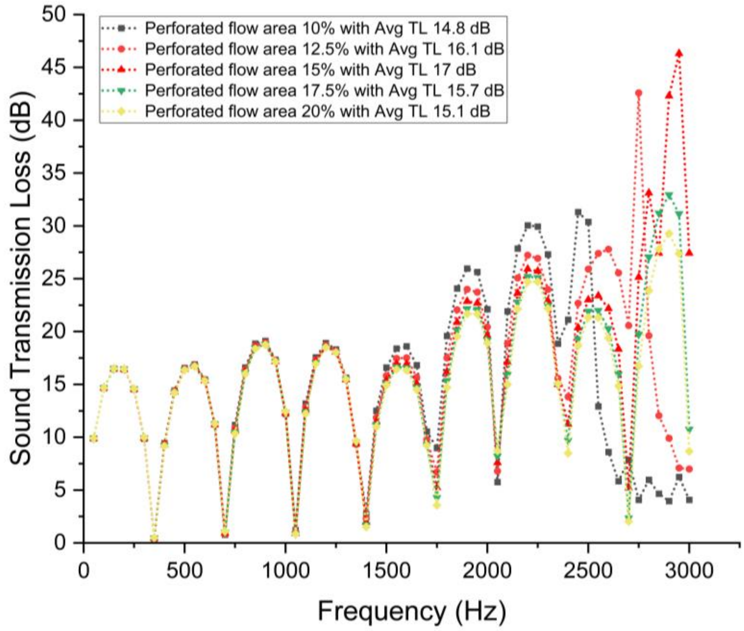

Figure 2: Comparison of muffler sound transmission loss under various perforated flow percentage

As this work is on hybrid muffler, the optimum design selected after perforation was filled with different absorptive material with filling density 20kg/m^3. The muffler was filled with S Glass, Powertex, Advantex, R Glass, ECR Glass and with Rockwool. The obtained results as shown below in figure 3.

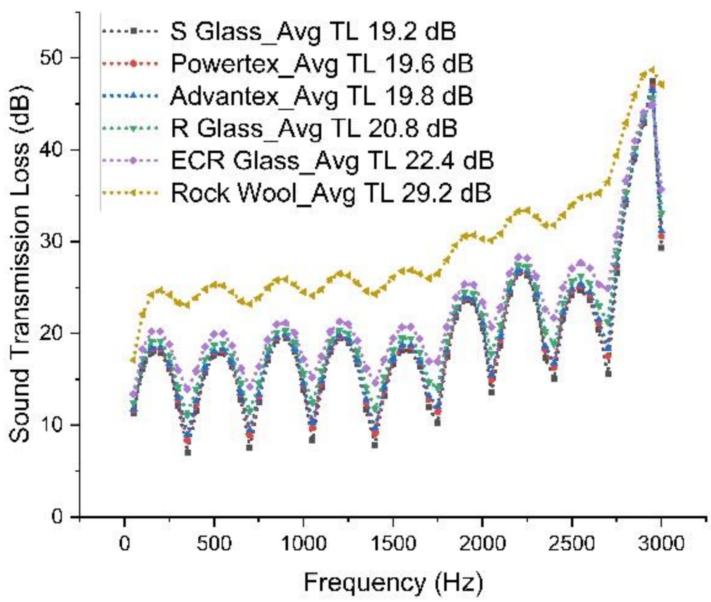

Figure 3: Comparison of muffler sound transmission loss with different sound absorbing materials

In this work, different materials with a density of 20 kg/m were filled in the muffler. In which the lowest STLis found in S glass with 19.2 dB, slightly higher in Powertex with 19.6 dB, similarly with Advantex 19.8 dB, 20.8 dBwith R glass, 22.4 dB with ECR glass and 29.2 dB with rock wool which was highest among.

Modelling for Acoustic Noise Control:

Various techniques are available analytically and theoretically to measure the STL like decomposition method, transfer matrix method, two load method, two source method and wave propagation method etc. In this present work as shown below in figure 4, we have designed the muffler using 3D tool in finite element analysis (FEA), then by changing the design of muffler, like inserting a perforated pipe, making compartment in the muffler and filled with same and mix material in the STL was determined and finding the condition in which maximum STL was obtained, The main focus has been on sound absorbing materials such as Powertex,Advantex, ECR Glass, R-Glass and S-Glass and the STL has been observed by filling them at different densities inside the mufflers

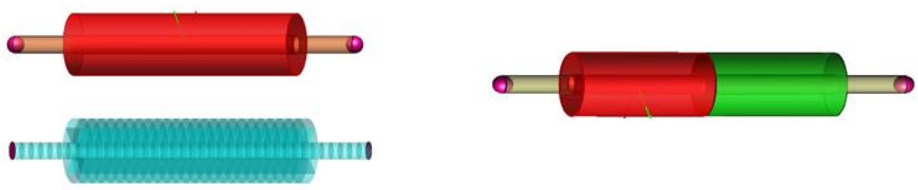

Figure 4: FEA model of muffler with single and double compartment

Computation of Sound Transmission Loss

The ratio of sound intensity between incident and transmitted waves, as indicated in Equation (1), serves as a mathematical representation of the transmission loss (TL) of the expansion chamber muffler depicted in Figure 5(b). The same cross-section of the intake and outflow is employed in this equation's application. The sound intensities of the incident and transmitted waves (Wi and Wt, respectively) are expressed using the plane wave theory in Equation (2). The amplitude ratio between incident and transmitted waves can be used to characterize the TL by substituting the equations for Wi and Wtfrom Equations (2a) and (2b) into Equation (1).

$$TL = 10\log_{10}\left(\frac{W_i}{W_t}\right)\ldots . \qquad (1)$$

$$I_i = \frac{1}{2}\frac{A_3A_3^*}{\varphi C} = \frac{1}{2}\frac{|A|^2}{\rho C}\ldots\ldots\ldots\ldots \qquad (2\ a)$$

$$I_t = \frac{1}{2}\frac{A_3A_3^*}{\varphi C} = \frac{1}{2}\frac{|A_3|^2}{\varphi C}\ldots\ldots\ldots \qquad (2b)$$

$$TL = 10log_{10}\left|\frac{A_1}{A_3}\right|^2\ldots\ldots\ldots\ldots \qquad (3)$$

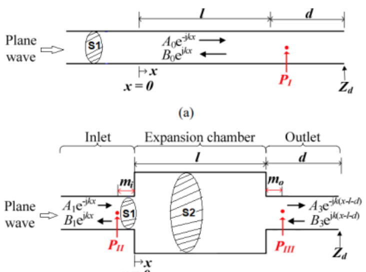

Figure 5: Mathematical analysis models were employed to assess noise attenuation with: (a) only duct (b) duct with muffler

VALIDATION OF EXPERIMENTAL SETUP

A muffler setup was made in the laboratory and with the help of amplifier, sound analyzer by installing speaker and load in it, it was seen that how much STL is being caused by the empty muffler. Thereafter sound absorbing materials like glass wool, rock wool was physically filled inside the muffler and it was observed what is the change in STL. After this the same design is designed in FEA and after performing wave analysis error is calculated to see how much difference is there in the STLof both. The percentage of error is 5% to 7% which indicates that finite element analysis can be done. After verification of wave analysis result various alternative design changes have been made to the mufflers with control volume analysis and STLhas been determined. It has also been calculated by making different compartments in the muffler and filling different materials at different percentage level and at different density level.

This experimental setup utilizes a hybrid absorptive muffler enclosed with various components. These components include two microphones, a speaker with AU-60 capacity, and a defined load. The setup is connected to an amplifier, sound analyzer, and a software gadget. The purpose of the experiment is to study frequencies ranging from 50 to 3000 Hz.To cover the entire frequency range effectively, measurements are divided into two parts: one between locations 1 and 1', and the other between locations 4 and 4' (as shown in Figure 6). For measuring pressure within the frequency range of 50 to 400 Hz, the designated sites 1-2-3-4 are utilized. On the other hand, locations 1'-2-3-4' are used for measuring pressure within the frequency range of 400 to 3000 Hz. This division ensures accurate data collection across the desired frequency spectrum.

Figure 6: Experimental test rig setup for the evaluation of Transmission Lossfor Hybrid Muffler

The experimental setup consists of a circular muffler featuring an internal perforated tube coaxially positioned within an exterior cylindrical tube. Circular flanges are installed on both ends of the internal tube to cover the two ends of the exterior cylindrical chamber. The perforated pipe used in the setup has an internal diameter of 35 mm, while the expansion chamber is 500 mm long and has a diameter of 130 mm.To evaluate the STLperformance, two different materials have been chosen: glass fiber and rock wool. The muffler is filled with these materials at various packing densities, namely 60 kg/m^3, 80 kg/m^3, and 100 kg/m^3, as shown in Figure 7. The purpose of this setup is to study and compare the sound transmission characteristics of the muffler under different packing densities using these selected materials.

Figure 7: The unfilled muffler compartment comprises two main materials: (a) Glass wool and (b) Rock wool.

In Figure 8, a comparative analysis of STLis presented for two different materials, (a) Glass wool and (b) Rock wool, at the same intensity level. Wave 1-D analysis and experimental validation serve as the foundation for this analysis. Practical measures are used in the experimental validation to ascertain the muffler's properties for STLwhen packed with glass wool and rock wool. Conversely, wave 1-D analysis makes use of theoretical simulations to examine the behavior of sound transmission under the same circumstances.

Additionally, the wave 1-D analysis enables the insertion of alternative design criteria, offering more details on how various design aspects affect the efficiency of sound transmission. The capabilities of the muffler's sound attenuation are better understood and optimized as a result of this thorough analysis, which takes into account different circumstances and design ideas.

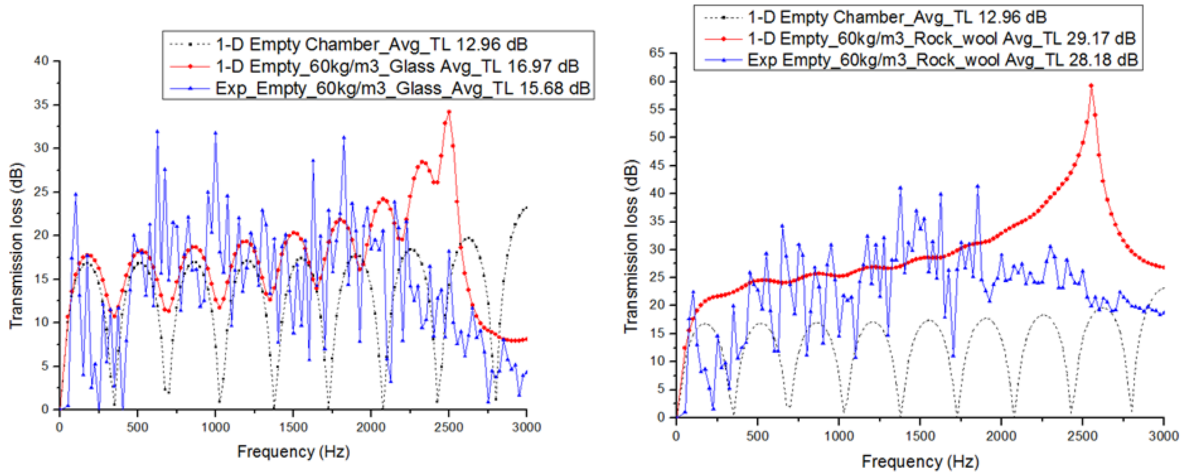

Figure 8: Comparative analysis of glass wool and rock wool with experimental setup

CONCLUSION AND FUTURE DIRECTIONS OF RESEARCH

In the original testing, the empty silencer showed a 12.5 dB loss in sound transmission. The surface area of the muffler's pipe was perforated, initially at 10% of the flow area, to improve its performance. This caused the STLto rise to 14.8 dB. By adjusting the perforated surface area, more changes were performed.

The STLincreased to 16.1 dB at 12.5% perforation and to 17 dB at 15% perforation. However, the STLstarted to reduce when the perforation was raised to 17.5%.Consequently, the 15% perforation of the flow area that was judged to be the best design to achieve the largest STL.

The optimized muffler design was then tested with various sound-absorbing materials. Rock wool displayed the maximum STLat 29.2 dB, while glass produced the lowest at 19.2 dB.

The combination of a perforated pipe and appropriate sound-absorbing materials playing a critical role in reaching the ideal STLlevels, these findings offer useful insights for building effective mufflers.

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REFERENCES

1. V. Cardin et al., “Resting-state functional connectivity in deaf and hearing individuals and its link to executive processing,” Neuropsychologia, vol. 185, p. 108583, 2023, doi: https://doi.org/10.1016/j.neuropsychologia.2023.108583.
2. A. Aydın Sayılan, N. Kulakaç, and S. Sayılan, “The effects of noise levels on pain, anxiety, and sleep in patients,” Nurs. Crit. Care, vol. 26, no. 2, pp. 79–85, 2021, doi: 10.1111/nicc.12525.
3. T. Münzel, T. Gori, W. Babisch, and M. Basner, “Cardiovascular effects of environmental noise exposure,” Eur. Heart J., vol. 35, no. 13, pp. 829–836, 2014, doi: 10.1093/eurheartj/ehu030.
4. M. Mir, F. Nasirzadeh, H. Bereznicki, P. Enticott, S. Lee, and A. Mills, “Construction noise effects on human health: Evidence from physiological measures,” Sustain. Cities Soc., vol. 91, p. 104470, 2023, doi: https://doi.org/10.1016/j.scs.2023.104470.
5. M. Guo, M. Y. Ni, R.-J. Shyu, J. S. Ji, and J. Huang, “Automated simulation for household road traffic noise exposure: Application and field evaluation in a high-density city,” Comput. Environ. Urban Syst., vol. 104, p. 102000, 2023, doi: https://doi.org/10.1016/j.compenvurbsys.2023.102000.
6. M. del M. D. del Amor, A. B. Caracena, M. Llorens, and F. Esquembre, “Tools for evaluation and prediction of industrial noise sources. Application to a wastewater treatment plant.,” J. Environ. Manage., vol. 319, p. 115725, 2022, doi: https://doi.org/10.1016/j.jenvman.2022.115725.

7. Y. L, K. P. Prashanth, B. K. Venkatesha, S. Sanman, and N. Venkatesh, “Investigation of light weight closed cell metallic foam for noise reduction in automobile application,” Mater. Today Proc., vol. 54, pp. 359–365, 2022, doi: https://doi.org/10.1016/j.matpr.2021.09.308.
8. D. D. Zhu and Z. L. Ji, “Transmission loss prediction of reactive silencers using 3-D time-domain CFD approach and plane wave decomposition technique,” Appl. Acoust., vol. 112, pp. 25–31, 2016, doi: 10.1016/j.apacoust.2016.05.004.
9. U. Chhibber, R. Kumar, S. Haldar, and R. N. Hota, “Design and analysis of a compact acoustic filter for broad band noise absorption,” Appl. Acoust., vol. 140, no. May, pp. 30–38, 2018, doi: 10.1016/j.apacoust.2018.05.011.
10. A. Kashikar, R. Suryawanshi, N. Sonone, R. Thorat, and S. Savant, “Development of muffler design and its validation,” Appl. Acoust., vol. 180, p. 108132, 2021, doi: 10.1016/j.apacoust.2021.108132.
11. L. Xiang, S. Zuo, X. Wu, and J. Liu, “Study of multi-chamber micro-perforated muffler with adjustable transmission loss,” Appl. Acoust., vol. 122, pp. 35–40, 2017, doi: 10.1016/j.apacoust.2017.01.034.
12. C. D. Gaonkar, D. R. Rao, K. M. Kumar, and M. L. Munjal, “End corrections for double-tuning of the same-end inlet-outlet muffler,” Appl. Acoust., vol. 159, p. 107116, 2020, doi: 10.1016/j.apacoust.2019.107116.
13. J. W. Lee, “Optimal topology of reactive muffler achieving target transmission loss values: Design and experiment,” Appl. Acoust., vol. 88, pp. 104–113, 2015, doi: 10.1016/j.apacoust.2014.08.005.