A review of the acoustic evaluation of reactive muffler with single expansion chamber for transmission loss

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Abstract

Internal combustion engines are a significant contributor to noise pollution in society, particularly in urban areas where traffic is dense. To mitigate this issue, mufflers are commonly installed at the end of the exhaust system to reduce the noise generated by the engine. The effectiveness of a muffler in reducing noise largely depends on the design and materials used in its construction. The way different components of the muffler interact with sound waves plays a crucial role in determining how much noise is suppressed. Consequently, it is essential to design mufflers that are as effective as possible in minimizing noise pollution. This study focuses on evaluating the Transmission Loss (TL) of a single expanding chamber reactive muffler, which is a common type of muffler used in exhaust systems. To measure the TL, the study employs a combination of three different approaches: theoretical analysis, finite element analysis using COMSOL Multi-Physics, and experimental analysis through the two-load method. By employing these diverse methods, the research aims to gain a comprehensive understanding of the muffler's performance and optimize its design for maximum noise reduction.

Keywords – Noise pollution, Muffler design, Transmission Loss, Reactive muffler, Transfer matrix Method, Finite Element Method (FEM), Experimental Method.

1. INTRODUCTION

The noise produced by internal combustion engines has been a significant environmental issue since the late 19th century. While structural noise and other sources contribute to engine noise, exhaust noise is the dominant factor, producing about 10 times the pressure of the other sources. As a result, reducing exhaust noise is the primary challenge in minimizing overall engine noise. Mufflers, or silencers, are acoustic devices installed in the exhaust systems of internal combustion engines to reduce this noise. They are also used in various other applications such as air conditioning units and compressors. Mufflers work by employing either absorptive or reactive principles to dampen noise. Absorptive mufflers absorb acoustic energy as sound waves pass through, thereby reducing noise transmission. Reactive mufflers, in contrast, rely on the impedance mismatch principle to reduce sound. An example of a reactive muffler is shown in Figure 1. To evaluate the performance of mufflers, key metrics like insertion loss (IL) and transmission loss (TL) are used. Specifically, transmission loss (TL) measures the muffler's ability to prevent sound radiation, offering insight into its acoustic effectiveness.

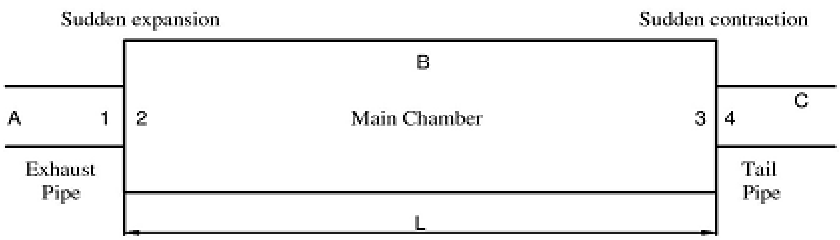

Figure 1: Single Chamber Reactive Muffler

The figure 1 shows single chamber reactive muffler. It includes exhaust pipe ,main chamber and tail pipe.

1.1 TYPES OF MUFFLERS:

Absorptive Mufflers: Utilizing absorption mechanisms, these mufflers reduce sound energy. Characterized by simpler designs and relatively lower back pressure, they excel in attenuating noise at higher frequencies but may exhibit limitations in reducing noise generated by exhaust gases at specific frequencies.

Reactive Mufflers: Comprising resonating and expansion chambers, reactive mufflers are engineered to decrease sound pressure levels at targeted frequencies, operating on the principle of impedance mismatch. Their construction aims to achieve optimal noise reduction.

Combination Muffler: A combination muffler integrates both reactive and absorptive elements to effectively reduce noise. This hybrid design leverages the strengths of both principles, combining sound absorption and reflection to optimize performance. Typically, a combination muffler consists of components such as chambers, baffles, and sound-absorbing materials, strategically arranged to enhance their noise-dampening capabilities. These mufflers are widely used in various applications, including automotive exhaust systems, motorcycles, generators, and industrial equipment, where comprehensive and efficient noise control is required. By blending the benefits of reactive and absorptive designs, combination mufflers provide a versatile solution for reducing exhaust noise.

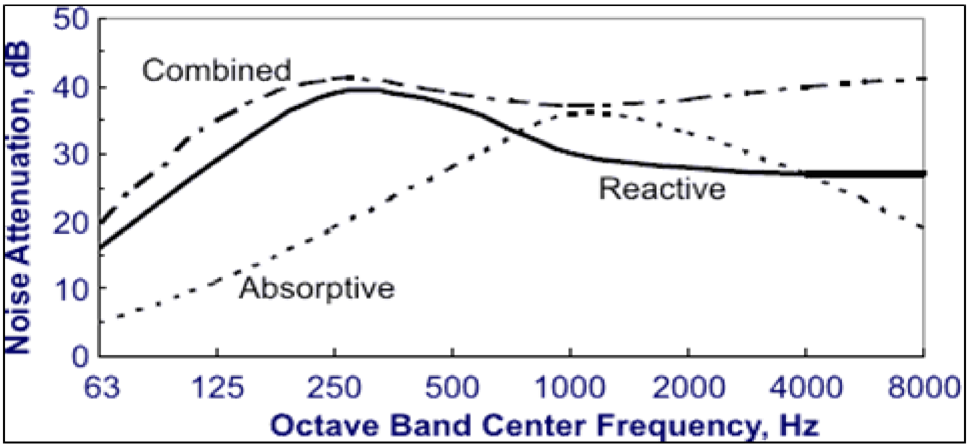

Figure 2: Noise attenuation curves for mufflers

Figure 2 compares the noise attenuation capabilities of reactive, absorptive, and combination mufflers. The results indicate that reactive mufflers are most effective at reducing higher frequency noise, while absorptive mufflers perform better at attenuating lower frequency noise. Combination mufflers, which combine both reactive and absorptive elements, provide a comprehensive solution by efficiently reducing noise across a broad range of frequencies.

2. Literature Review

In the paper "Prediction of Transmission Loss on a Simple Expansion Chamber Muffler" by Ujjal Kalita and Dr. Manpreet Singh, the authors focus on optimizing the design of a single expansion chamber muffler, specifically by considering the chamber's length and diameter as critical design parameters. The design process begins with the creation of the muffler model using CAD software, allowing for precise control over the shape and dimensions. Following this, acoustic simulations are performed using ANSYS to analyze the muffler's performance in reducing noise. The primary aim of the study is to predict the transmission loss (TL) based on the modified design and validate the results through comparisons with previous studies, including those by Milad et al. and Lee et al. The research highlights the importance of these design parameters in determining the muffler's effectiveness in attenuating sound. By comparing their findings with earlier works, the authors seek to confirm the reliability of their optimized design approach. This study not only provides valuable insights into the role of chamber geometry in muffler performance but also contributes to the development of more efficient muffler designs that can be applied in reducing engine noise in various applications. Ultimately, the research helps establish a clear relationship between theoretical modeling and practical muffler design, advancing strategies for noise control in internal combustion engines. [1][2][3][4].

The article *"Design and Analysis of Core Chamber of Muffler"* by Rameshwar Cambow explores the geometrical optimization of a simple expansion chamber muffler to enhance transmission loss. The study begins by selecting a range for the ratio of chamber diameter (D) to inlet tube diameter (d) based on a literature review. Simulations conducted in Ansys software reveal that the highest transmission loss occurs at a D/d ratio of 4.38. Further analysis examines the ratio of chamber length (L) to chamber diameter (D) within a range of 1.2 to 1.6, showing that an L/D ratio of 1.6 yields stable maximum transmission loss values. However, due to dimensional constraints, the study focuses on the L/D ratio of 1.3, which achieves a comparable maximum transmission loss of 22.055 dB. These findings provide a basis for designing and manufacturing optimized mufflers using the proposed geometric dimensions and ratios.[5],[6].

The article *"Investigation on Effect of Extended Inlet and Outlet Tubes on Single Expansion Chamber Muffler for Noise Reduction"* by Mahesh V. Kulkarni and Dr. Ravindra B. Ingle examines the acoustic performance of a single expansion chamber reactive muffler equipped with extended inlet and outlet tubes. The study aims to maximize sound transmission loss, analyzing a muffler with a length of 400 mm and a diameter of 110 mm, with inlet and outlet chambers measuring 44 mm in diameter and 80 mm in length. Modeling and meshing are carried out using COMSOL Multiphysics for numerical simulations, while theoretical analysis is conducted using MATLAB code based on derived formulas for uniform and extended tube configurations. The study evaluates transmission loss for four configurations: a standard single expansion chamber, and chambers with extended inlet, extended outlet, and both extended inlet and outlet. Results show that theoretical and numerical analyses produce closely matching transmission loss trends, validating the findings. The study concludes that mufflers with extended inlet and outlet tubes exhibit the lowest transmission loss among the configurations tested [7][8][9][10].

In the article *"Design and Analysis of Reactive Muffler for Enhancement in Transmission Loss"* by Tushar Sonkule, Suyash Dhadve, Akshay Shahane, Yash Malpani, and Mahesh Kulkarni, the authors explore various methods to evaluate the transmission loss of a single expansion chamber reactive muffler. The study includes both theoretical analysis and numerical simulations using COMSOL Multiphysics. For the theoretical analysis, the transmission loss was calculated based on fixed dimensions of the expansion chamber (540 mm in length and 120 mm in diameter) and the inlet/outlet pipes (44 mm in diameter). Numerical simulations were conducted with COMSOL, where the muffler was meshed using tetrahedral elements, and the Helmholtz equation was applied to determine sound pressure and transmission loss. The results from both methods showed strong agreement, confirming the reliability of both approaches. Additionally, experimental validation was carried out using the two-load method, where transmission loss was calculated using four microphone positions and pole equations. Two different loads were applied to ensure stable results. The experimental and numerical results showed good consistency, though a slight discrepancy was noted, likely due to factors such as sound leakage, white noise from the FFT, and surface finish variations in the impedance tube. The study concluded that the maximum transmission loss corresponded to the lowest radiated noise at a given frequency.[11][12]

The study "Acoustic Analysis and Modelling of Reactive Muffler to Reduce Noise of the System" by Dr. Mahesh V. Kulkarni and Akshay Vijay Shinde investigates the effect of baffle plate configurations on the acoustic performance of reactive mufflers. The researchers used numerical simulations in COMSOL Multiphysics and experimental analysis through the two-load method to model three muffler designs: a single baffle plate muffler with extended inlet-outlet, a double baffle plate configuration, and a triple baffle plate setup with varying circumferential diameters. All designs had a chamber diameter of 60 mm and a length of 560 mm. The results indicated that the single baffle plate design achieved the highest transmission loss of 58 dB, while the triple baffle plate model, with equally spaced plates, showed the most balanced performance, with a maximum transmission loss of 27 dB and an average of 16 dB. These findings emphasize the crucial role of baffle plate placement in optimizing muffler performance for noise reduction. [13],[14][15][16].

In the article *"Validation of Setup for Experimental Analysis of Reactive Muffler for the Determination of Transmission Loss,"* Mahesh V. Kulkarni and Ravindra B. Ingle discuss the use of mufflers to mitigate noise and vibration, particularly in automotive exhaust systems. The paper focuses on accurately predicting the sound radiation characteristics of reactive mufflers using the transmission loss (TL) method, which measures the difference between the power entering a muffler and the power transmitted downstream. To assess the muffler's acoustic performance, the authors create an experimental setup based on the two-load method, which is validated by comparing its results to those obtained using the finite element method (FEM). The study uses COMSOL Multiphysics to perform three-dimensional FEM analysis, assuming a zero Mach number and excluding fluid-structure interaction. The results from the experimental analysis are compared with those from the FEM, showing that the experimental setup is reliable for determining the transmission loss of exhaust mufflers in the low to mid-frequency range.[17][18][19].

In the article *"Acoustic Analysis of Single Expansion Chamber Reactive Muffler with Single Baffle for Maximum Transmission Loss,"* Mahesh Kulkarni explores the acoustic performance of a single expansion chamber muffler, focusing on achieving maximum transmission loss, particularly in generators where transmission loss can be a limiting factor. The research investigates the impact of baffles, including how varying baffle positions relative to the inlet and outlet affect the muffler's performance. By comparing theoretical and numerical analysis methods, the study shows their consistency, streamlining the muffler analysis process. The results indicate that using baffles increases transmission loss, especially when the baffle hole diameter is reduced, although this also raises back pressure, which limits the smallest diameter to the size of the inlet. The positioning of the baffle is also crucial, with the study finding that transmission loss is higher when the baffle is placed closer to the inlet and outlet [20][21].

In the article *"Design Development and Analysis of a Single Expansion Chamber for a Diesel Engine,"* Chinmayeev Askhedkar and Sagar C. Atre focus on designing a reactive muffler for a single-cylinder diesel engine to maximize transmission loss, which is crucial for muffler performance and efficiency. The study investigates how the muffler's shape and dimensions, including length, expansion ratio, and number of resonating chambers, influence its acoustic performance. The researchers optimize the muffler's length and expansion ratio while considering manufacturing constraints. Transmission loss for the optimal design is mathematically modeled using the Transfer Matrix Method and analyzed with the Finite Element Method (FEM). Both models are compared for accuracy. The study finds that transmission loss increases with the muffler's length and expansion ratio, achieving a maximum attenuation loss of 20 dB. The results from both models are validated through comparison, demonstrating their reliability in predicting muffler performance across varying dimensions and firing frequencies [22][23].

In the paper "Optimization and Experimental Validation of Elliptical Reactive Muffler with Central Inlet Central Outlet," Anant W. Wankhade and Dr. A. P. Bhattu present a practical solution for reducing tailpipe noise levels. The study uses acoustic analysis to assess muffler performance, with optimization achieved through Finite Element Analysis (FEA). The muffler design is initially modeled using PRO E Wildfire 5.0, and the acoustic analysis is conducted using COMSOL Multiphysics. The research focuses on two main factors: the extrusion of the inlet and outlet pipes within the chamber and the positioning of a divided inlet tube inside the chamber, with the goal of reducing sound pressure levels (SPL) or increasing transmission loss (TL). Although the effects of SPL on muffler walls and material considerations are not addressed, the optimized elliptical muffler model is manufactured and experimentally tested. The results from the Finite Element Method (FEM) analysis are compared with experimental outcomes, showing good agreement and validating the muffler's performance. [24][25][26].

In the paper "Acoustic Analysis of Extended Inlet and Outlet Tube Parameters in Single Expansion Chamber Reactive Muffler for Increment in Transmission Loss," Dr. Mahesh Kulkarni, Tushar Sonkule, Suyash Dhadve, Akshay Shahane, and Yash Malpani examine the potential of extended inlet and outlet tubes to improve transmission loss in mufflers. The study addresses the growing concern of noise pollution from internal combustion engines, which can negatively impact human health, particularly when noise levels exceed 80 dB. The research uses three methods: theoretical analysis, finite element analysis with COMSOL Multiphysics, and experimental validation through the two-load method. The theoretical analysis calculates transmission loss (TL) based on parameters such as expansion ratio (m), wave number (k), sound velocity (c), and chamber length (l), aiming to optimize muffler designs for enhanced noise reduction [27][28][29].

3. Conclusion

The research paper examines a single expansion chamber reactive muffler using both theoretical and numerical analysis. The theoretical approach utilizes a MATLAB program to calculate transmission loss, taking into account factors such as extended inlet and outlet pipes, as well as baffles. The numerical analysis is performed using COMSOL Multiphysics, which models, meshes, and analyzes the muffler's acoustic performance in the frequency domain. The findings indicate that modifications to the internal geometry, like extending the inlet and outlet, lead to an increase in transmission loss, highlighting that optimization can enhance acoustic performance. The study underscores the significance of both theoretical and numerical methods in optimizing muffler design and includes experimental validation using the two-load method, confirming the accuracy and reliability of the numerical results.

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Competing interests

The author have no competing interests to declare that are relevant to the content of this article.

References

1) Kalita, U. (2018). Prediction of transmission loss on a simple expansion chamber muffler. *Journal of Emerging Technologies and Innovative Research, 5*(8), 1022–1031.

2) Kulkarni, M. V., & Ingle, R. B. (2018). Effect of extended inlet and outlet placement on transmission loss of double expansion chamber reactive muffler. *International Journal of Research and Analytical Reviews, 5*(4), 552–558.

3) Khanzode, P. S., & Kulkarni, M. V. (2019). Acoustic analysis and optimization of double expansion chamber reactive muffler for maximum transmission. *International Journal of Scientific & Technology Research, 8*(9), 2351–2355.

4) Kulkarni, M. (2024). An in-depth study of the acoustics of a single expansion chamber reactive muffler. *International Journal of Research and Analytical Reviews, 11*(1), 259–265.

5) Cambow, R. (2019). Design and analysis of core chamber of muffler. *International Journal of Research and Analytical Reviews.* Retrieved from www.ijrar.org

6) Kulkarni, M., & Jadhav, S. (2023). Acoustic analysis of single expansion chamber reactive muffler - A critical review. *International Journal of Scientific Engineering and Research, 11*(1), 37–42.

7) Kulkarni, M. V., & Ingle, R. B. (2017). Investigation on effect of extended inlet and outlet tubes on single expansion chamber muffler for noise reduction. *American International Journal of Research in Science, Technology, Engineering & Mathematics, 18*(1), 10–15. Retrieved from http://www.iasir.net

8) Kulkarni, M. (2023). Evaluation of extended inlet and outlet tube parameters in single expansion chamber reactive muffler. *YMER, 22*, 1134–1142.

9) Kulkarni, M., & Ingle, R. (2020). Effect of variations in extended inlet lengths for constant extended outlet lengths on transmission loss of double expansion chamber reactive muffler. *Journal of Seybold Report, 15*(3), 2318–2324.

10) Kulkarni, M., & Ingle, R. (2022). Effect of extended inlet and outlet lengths on transmission loss of double expansion chamber reactive muffler. *International Journal of Vehicle Structures and Systems, 14*(2), 135–137. https://doi.org/10.4273/IJVSS.14.2.01

11) Sonkule, T., Dhadve, S., Shahane, A., Malpani, Y., & Kulkarni, M. (2021). Acoustic analysis of extended inlet and outlet tube parameters in single expansion chamber reactive muffler for increment in transmission loss. *International Research Journal of Engineering and Technology, 8*(6), 2589–2595.

12) Ghodke, N. A., & Kulkarni, M. V. (2018). Experimental and numerical evaluation of exhaust back pressure of double expansion chamber reactive muffler. *International Journal of Research and Analytical Reviews, 5*(2), 351–354. Retrieved from www.ijrar.org

13) Shinde, A. V., & Kulkarni, M. V. (2021). Acoustic analysis and modelling of reactive muffler to reduce noise of the system. *International Journal of Scientific & Engineering Research, 12*(6), 535–539. https://doi.org/10.17577/ijertv5is050386

14) Sonkule, T., Dhadve, S., Shahane, A., Malpani, Y., & Kulkarni, M. (2021). Acoustic analysis of extended inlet and outlet tube parameters in single expansion chamber reactive muffler for increment in transmission loss. *International Research Journal of Engineering and Technology, 8*(6), 870–876. Retrieved from www.irjet.net

15) Kulkarni, M. (2023). A critical study of the acoustic evaluation of a double expansion chamber reactive muffler. *International Journal of Research and Analytical Reviews, 10*(1), 528–533.

16) Jadhav, S., & Kulkarni, M. (2023). A critical review of acoustic investigation of double expansion chamber reactive muffler. *International Journal of Research and Analytical Reviews, 10*(2), 713–718.

17) Kulkarni, M. V., & Ingle, R. B. (2018). Validation of set-up for experimental analysis of reactive muffler for the determination of transmission loss: Part 1. *Noise and Vibration Worldwide, 49*(6), 237–240. https://doi.org/10.1177/0957456518781857

18) Kulkarni, M. V., & Ingle, R. B. (2018). Attenuation analysis and acoustic pressure levels for double expansion chamber reactive muffler: Part 2. *Noise and Vibration Worldwide, 49*(6), 241–245. https://doi.org/10.1177/0957456518781859

19) Kulkarni, M., Kuhikar, P., Shaikh, B., Chitre, S., & Jamal, S. (2023). Effect of internal geometry change on transmission loss (TL) of double expansion chamber reactive muffler. *AIP Conference Proceedings, 2821.* https://doi.org/10.1063/5.0158561

20) Patil, A., Kulkarni, C., Bhujbal, O., Shete, S., & Kulkarni, M. (2021). Acoustics analysis of single expansion chamber reactive muffler with single baffle for maximum transmission loss. *International Journal of Advances in Engineering and Management, 3*(7), 833–839. https://doi.org/10.35629/5252-0307833839

21) Shirode, P., Lokhande, A., Shete, A., Mohite, D., & Kulkarni, M. (2022). Effect of baffle placement on transmission loss of single expansion chamber reactive muffler. *International Journal of Research and Analytical Reviews, 9*(3), 24–34.

22) Askhedkar, C., & Atre, S. C. (2020). Design, development, and analysis of a single expansion chamber for a diesel engine. *International Research Journal of Engineering and Technology, 5*(8), 1076–1080.

23) Shirode, P., Lokhande, A., Shete, A., Mohite, D., & Kulkarni, M. (2022). Review of acoustic analysis of single expansion chamber reactive muffler. *International Journal of Research and Analytical Reviews, 9*(2), 635–640.

24) Wankhade, A. W., & Bhattu, A. P. (2015). Optimization and experimental validation of elliptical reactive muffler with central inlet central outlet. *International Journal of Engineering Research and Technology, 4*(5), 1321–1328. https://doi.org/10.17577/ijertv4is051209

25) Kulkarni, M. V., & Ingle, D. B. (2018). Finite element analysis of double expansion chamber reactive muffler with side outlet. *International Journal of Research and Analytical Reviews, 5*(2), 758–764. Retrieved from http://ijrar.com/

26) Ingle, R., & Kulkarni, M. (2020). Acoustic analysis and optimization of double expansion chamber reactive muffler using Taguchi method. *Journal of Seybold Report, 15*(2), 1844–1855.

27) Kuhikar, P., Shaikh, B., Chitre, S., Jamal, S., & Kulkarni, M. (2022). Review on acoustic analysis of double expansion chamber reactive muffler. International Journal of Research and Analytical Reviews, 9(1), 26–32.

28) Salunkhe, S., Dayne, S., & Kulkarni, M. (2022). Review paper on analysis of reactive muffler for enhancement in transmission loss. Research Journal of Science Engineering and Technology, 12(1), 34–39.

29) Salunkhe, S., & Kulkarni, M. (2023). Optimization of extended inlet length and extended inlet diameter of single expansion chamber reactive muffler for maximum transmission loss in a specific frequency range. YMER, 22, 708–721.