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Behavior of transmission loss in muffler with the variation in absorption layer thickness

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Abstract: *This paper reveals the acoustic performance of packed dissipative muffler with the variation in thickness of absorption material. It researches the sound absorbing capacity of different mufflers on application of this absorption material and also predicts one of the suitable designs of muffler for application in automobile industry. Delany-Bazley equations are used for the application of properties to the absorption materials. This study is performed to reduce the noise coming out of the exhaust system of vehicles as noise pollution and excessive exhaust smoke affect the environment. Transmission Loss (TL) which is the main acoustic performance parameter is evaluated as it determines the reduction in exhaust noise. This is performed in the 3D linear pressure acoustic module of Comsol Multiphysics. Polyester, Ceramic Acoustic Absorber and Rockwool are the materials taken for study.*

Keywords: Absorption material, Packed dissipative muffler, Transmission Loss, Thickness, Ceramic acoustic absorber with silicon carbide fibers

1. INTRODUCTION

Noise and pollution emitted by the vehicles exhaust system and some large industries are the main concern for the people as it affects the environment to a large extent. Muffler is a tool that can be used for the reduction of this noise. There are some parameters on which the performance of this muffler depends. Transmission Loss (TL), Insertion Loss (IL) and Level difference are the three acoustic performance parameter of the muffler. Of these various parameters, transmission loss is the main parameter which is taken into consideration by most. The main objective of a muffler is to reduce the anechoic termination at the exhaust of the muffler. So transmission loss is the parameter which is most favorable for this termination. It is because

1. It is the property of the muffler alone and it doesn't depend on the source (its position and strength)
2. It is easily predictable but difficult in measuring as it is difficult to achieve anechoic termination easily.

The increase and decrease of the TL depends on the type of acoustic filters fitted in the muffler. Helmholtz resonator, absorption material, perforated tube, uniform tube are some of these filters. In this work absorption material is utilized in the muffler. Polyester, Rockwool are some of the absorption materials that are used by different researchers. Ceramic acoustic absorber with silicon carbide (SiC) fiber is one such material which is used for study in this work. It has excellent sound absorbing and thermal resistance capability [6]. It can resist heat to a temperature of about 1800ºC to 2300ºC. The mean diameter of the material is 500- 3400 µm near the rear surface and 50- 450 µm near the front surface of the body. This material has void ratio of 80 – 92 %, so it can act as a perforated body. The flow resistivity is in range of 4 to 60 [CGS Rayls/cm].

2. EVALUATION OF TRANSMISSION LOSS

Transmission loss is the ratio of sound power of the incident (progressive) pressure wave at the inlet of muffler to the sound power of the transmitted pressure wave at the outlet of the muffler. It can be expressed as

$$\mathrm{TL} = 10\log\frac{\text{(incident energy)}}{\text{(transmitted energy)}} \tag{1}$$

$$\text{i.e. } \mathrm{TL} = 20\mathrm{Log}\left(\left|\frac{p_{inc.}}{p_{trans.}}\right|\right) + 10\,\mathrm{Log}\left(\frac{S_o}{S_i}\right) \tag{2}$$

The transmission loss can be also be determined by transfer matrix method where it is calculated by the 4- pole parameter of the muffler.

$$\mathrm{TL} = 20\mathrm{Log}_{10}\left(\left|\frac{1}{2}\left[A + \frac{B}{\rho_o c} + (\rho_o c)C + D\right]\right|\right) + 10\mathrm{Log}_{10}\left(\frac{S_o}{S_i}\right) \tag{3}$$

Here A, B, C and D are the 4 poles and S_o and S_i are the area of the outlet and inlet tube.

3. LITERATURE SURVEY

According to current survey different researchers have performed different works on the muffler. Selamet Et al and Munjal [2,3] performed various works on mufflers. They studied the different parameters associated with the muffler also on the geometric features that could be utilized .Munjal also wrote a book on the function and properties of muffler, “Acoustics of ducts and mufflers with application to exhaust and ventilation system” [1]. With the passing years, there is some advancement in the numeric and simulation methods like FEM and CFD. Selamet worked in this with some of the scientists where he also considered the effect of temperature. Xu Et Al (2004) used the two-dimensional analytical approach, and examined the effect of fiber thickness, chamber diameter and material properties on the acoustic performance of dissipative silencers. This analytical approach was proposed and based on the solution of Eigen equations for a circular dissipative expansion chamber. In their work the acoustic pressure and particle velocity across the silencer discontinuities were matched by imposing the continuities of the velocity/pressure which is integrated over discrete zones at the expansion or contraction [4]. Mehdizadeh Et Al. (2005) performed his work in packed muffler. He used the three dimensional finite element methods to predict the transmission loss of a muffler for a wide frequency range. A hybrid muffler with perforated pipes and absorbing materials was implemented and transmission loss is calculated by using finite element method. These results were compared with the results obtained through numerical methods and found an increase in transmission loss [5]. F.D. Denia, A. Selamet, F.J. Fuenmayor and R. Kirby (2007) performed their work by considering absorbent resistivity, extended inlet/outlet ducts and the porosity of the perforations. Fiber materials are used as the absorption material and it was found that increase in radii and chamber length leads to higher transmission loss [7,9]. Ji Et Al. (2008) used the GT Power software for the design and simulation of muffler. He incorporated the mass flow rate at an elevated temperature. His work showed that there was an increase of around 10 to 15 dB at a flow of 60 m/s across the entire frequency range and mostly at higher frequencies. He performed his experiments in a three pass perforated muffler [8]. Like this several other researchers such as Siano et al. determined the TL of a three pass muffler configuration using both GT-Power for 1-D simulation and STS VNoise for 3-D BEM [10] and Anderson (2010) implemented the mass flow into the FEM model indirectly by considering the boundary conditions [11] Zheng Et Al. (2011) used coupled hybrid approach and included the source properties from the one dimensional method to the muffler’s 4-pole parameters obtained by the 3-D FEM techniques. The 4-pole parameters take the state variables; pressure and mass particle velocity present at the inlet and outlet of the muffler [12]. A.G. Antebas, F.D. Denia, A.M. Pedrosa, F.J. Fuenmayor (2013) didn’t use perforated tube and exposed the fibrous material to the gases in the central airway. It was found that a TL of about 50-60 dB occur at frequency range of 1000-1500 Hz [13].In an article by me and my co-authors Abhijeet Pratap and Sushil Kumar (2015) had described some of the absorption materials that are used in recent times in muffler and also some that could be used in coming years [14].

4. METHODOLOGY

4.1 Approaches for muffler analysis

The mufflers are studied and analyzed in various ways. The first approach that is used for this analysis is the one dimensional frequency domain based upon the electro acoustic analogy. Another approach is the one dimensional time domain. Here the equations are evaluated numerically in the time domain to determine all acoustic waves simultaneously. Plane wave analysis could determine the muffler performance accurately as only one dimensional is considered. Because of this earlier muffler models are determined through trial and error methods. Now a day’s different numerical analysis of mufflers are performed with boundary element (BEM) and finite element method (FEM). This could be performed with different FEM solvers available such as M.Sc. Actran, ANSYS and LMS Virtual. Lab.

In this study the muffler is analyzed by using the three dimensional finite element methods. ‘Comsol Multiphysics’ is used for solving the fem. Here the model depicts the pressure wave propagation of muffler for Internal Combustion Engine. The approach is usually applied to analyze the damping of propagation of harmonic pressure waves. Its main objective is to simulate and analyze both inductive and resistive dumping in pressure acoustics and its main output is to determine the transmission loss for some frequency range.

4.2 Process of simulation and analysis

In this software the problem is solved in the 3D linear pressure acoustic time harmonic analysis.

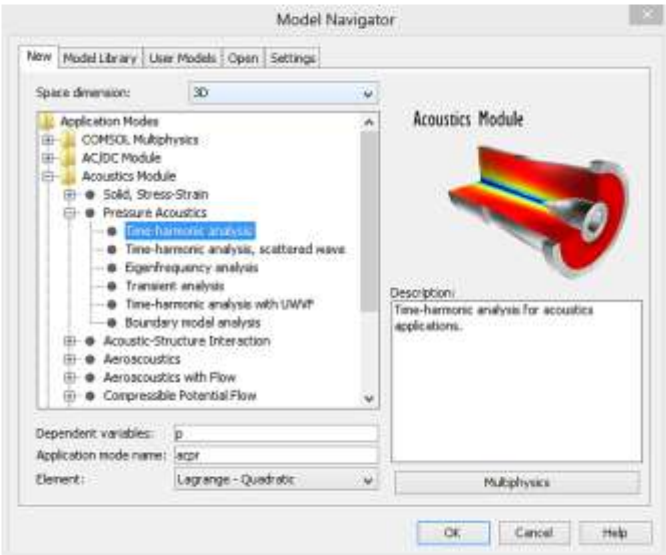

Figure 1 : Selection of interface

Helmholtz equation is the model’s governing equation

$$\nabla\left(-\frac{\nabla p}{\rho}\right)-\frac{\omega^2 p}{{c_s}^2\rho}=0 \qquad (4)$$

Here ρ = density,

ω = angular frequency,

c_s = speed of sound.

The model is then created with the different tools available.

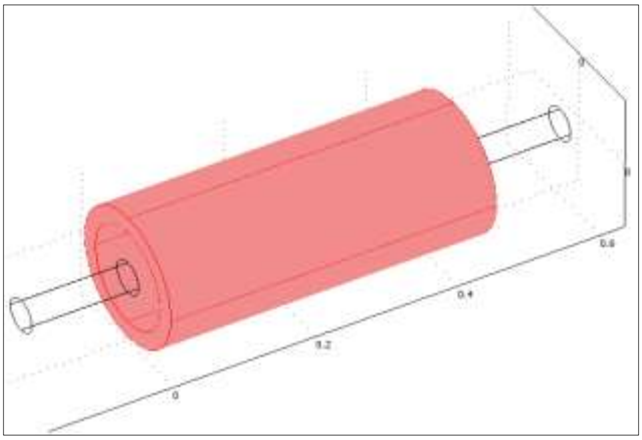

Figure 2 : Modeling of chamber

Now we are required to give the different boundary conditions.

1. At the inlet, pressure wave is taken as 1 Pa and at the outlet radiation condition is taken.
2. All the outer boundaries are taken as solid hard wall boundary.

For a cross-section of the chamber, wave number and mode shape is obtained through eigenvalue problem

$$\nabla.\left(-\frac{\nabla p(y,z)}{\rho_o}\right)-\left(\frac{\omega^2}{\rho_o c^2}-\frac{K_x{}^2}{\rho_o}\right)p(y,z)=0 \qquad (5)$$

The cut off frequency for each mode is obtained by

$$f_j=\frac{\sqrt{\omega^2-c^2K_x{}^2}}{2\pi} \qquad (6)$$

The model is now meshed with the free meshing parameters and it then put for the post processing process. In this analysis is performed with acoustic frequency range from 100 Hz to 3000 Hz.

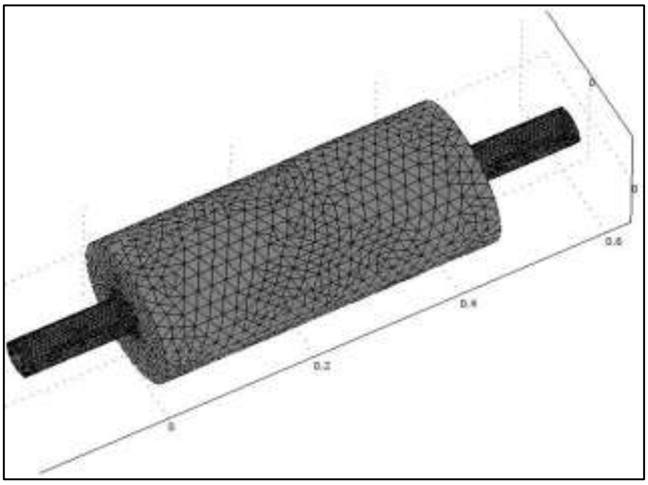

Figure 3 : Meshing of muffler

The equation which defines the attenuation (dB) of the acoustic energy is

$$TL=10*\log\left(\frac{w_i}{w_o}\right) \qquad (7)$$

Where w_i and w_o are the incident power and the transmitted power respectively.

$$w_i=\frac{p_o{}^2}{2*rho_{acpr}*c_{s_{acpr}}} \qquad (8)$$

$$w_o=\frac{abs(p)}{2*rho_{acpr}*c_{s_{acpr}}} \qquad (9)$$

5. VALIDATION OF THE METHOD

Mehdizadeh Et Al. performed their work in FEM and they did this through mathematical modeling. The amount of transmission loss produced from his work is almost same when we performed his work in 'COMSOL' simulation software. From this we can say that the method used by this software is accurate and could be applied for the transmission loss determination.

6. RESULT AND DISCUSSIONS

Two designs are considered for analysis in this study.

Table 1 : Specifications of muffler

	Design 1		Design 2	
	Length (cm)	Diameter (cm)	Length (cm)	Diameter (cm)
Chamber	45.72	10.16	50	10
Inlet and outlet	15	5.08	9.6	5.1

Table 2 : Air flow resistivity of absorbing materials

Materials	Flow resistivity[Rayls/m]	Melting point[°C]
Polyester	16000	250
Rockwool	13813	1000
Ceramic acoustic absorber	6060	1800 - 2300

In this study we are evaluating the transmission loss produced on application of absorption material in the muffler. The analysis is performed with 15 mm, 25 mm, 30 mm and 35 mm thickness absorption lining. All the analyses are performed in the frequency range 100 Hz to 3000 Hz.

6.1 For design 1 and 2 with polyester lining

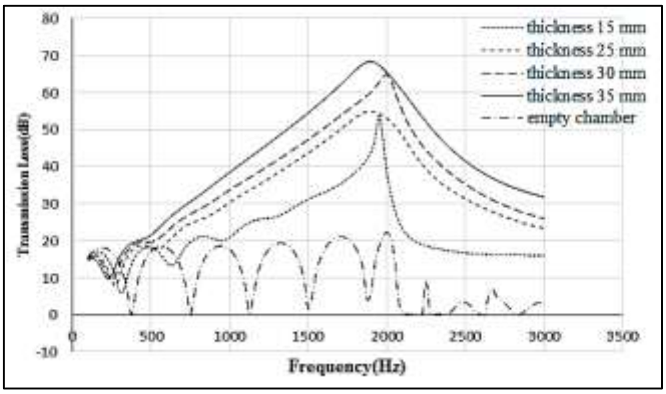

Figure 4 : TL of muffler on varying the thickness of the absorption material (polyester) for design 1

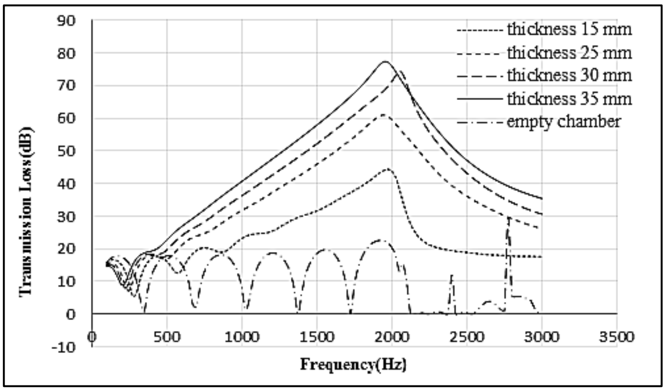

Figure 5 : TL of muffler on varying the thickness of the absorption material (Polyester) for design 2

From the above figures it is noted that as the thickness of absorption material is increased the maximum transmission loss (TL) is increased. This occurs in the frequency range 1900 Hz to 2100 Hz for both the muffler.

6.2 For design 1 and 2with Rockwool lining

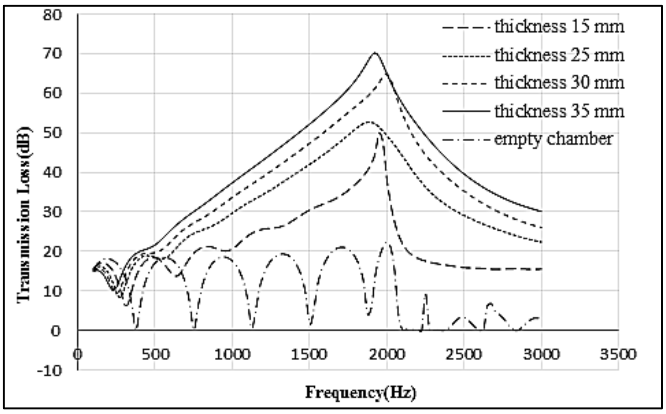

Figure 6 : TL of muffler on varying the thickness of the absorption material (Rockwool) for design 1

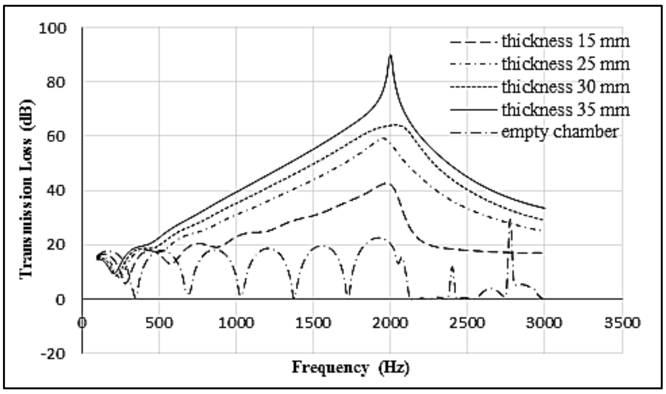

Figure 7 : TL of muffler on varying the thickness of the absorption material (Rockwool) for design 2

These figures also reveal that increase in thickness of absorption layer increases the maximum transmission loss.

6.3 For design 1 and 2 with ceramic acoustic absorber

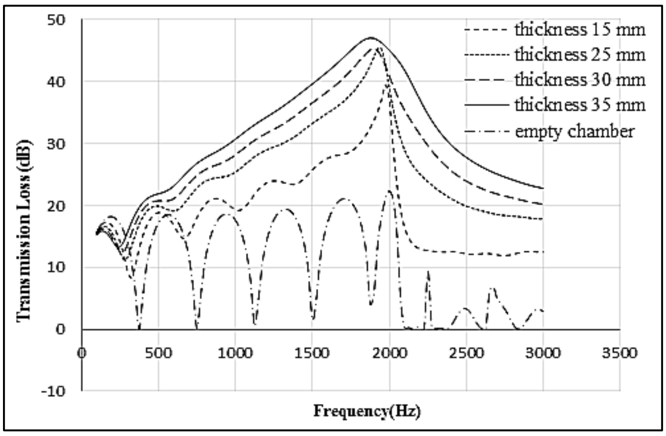

Figure 8 : TL of muffler on varying the thickness of the absorption material (ceramic acoustic absorber) for design 1

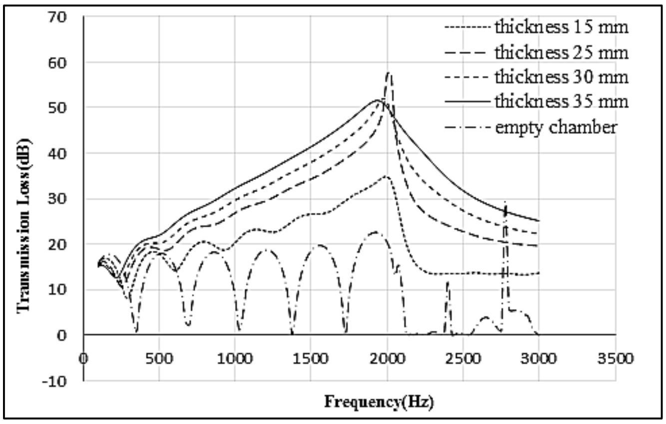

Figure 9 : TL of muffler on varying the thickness of the absorption material (ceramic acoustic absorber) for design 2

From figure 5 it is found that the maximum transmission loss is almost same for 25 mm and 30 mm absorption layer. From figure 6 it is found that decrease in absorption layer thickness, increases the maximum transmission loss but it contradicts with 15 mm layer thickness.

Table 3 : TL on application of different absorption material for design 1

		Design 1			
Thickness (mm)		15	25	30	35
Maximum Transmission Loss (dB)	Polyester	54	55	65	68
	Rockwool	50	53	65	70
	Ceramic acoustic	39	45	45	47

Table 4 : TL on application of different absorption material for design 2

		Design 2			
Thickness (mm)		15	25	30	35
Maximum Transmission Loss (dB)	Polyester	44	61	74	77
	Rockwool	43	59	64	90
	Ceramic acoustic	35	58	52	51

7. CONCLUSION

From the analysis it is found that design 2 produces more TL than design 1.It is also found that TL increases with the increase in thickness of absorption layer for polyester and Rockwool. But on application of Ceramic Acoustic Absorber with SiC fibers, it is found that the muffler with 25 mm absorption lining of it produces the maximum TL than the muffler with 15 mm or 35 mm absorption lining. So it can be concluded that if we are applying Ceramic Acoustic Absorber as absorption material, we have to use only 25 mm thickness layer. Also it is found that on applying 25 mm thickness absorption lining of this material there is not much difference in maximum TL with application of the other material. But the heat resisting capacity of polyester is 250 ºC, Rockwool 1000 ºC, whereas for Ceramic Acoustic Absorber it is 1800 ºC to 2300 ºC. Thus the muffler with Ceramic Acoustic Absorber lining of 25 mm will be the most effective muffler. Further if we consider the effect of weight than it is found that application of Rockwool Lining in muffler would reduce the weight by almost 50% and is also effective as it can resist heat to a temperature of 1000 ºC .

From the analysis it can also be concluded that TL is maximum in the frequency range where the sound pressure level is minimum i.e. around 6 dB. It is produced in the frequency range of 1800 Hz to 2200 Hz. The TL increases with the increase in air flow resistivity. Thus in all respect design 2 would be the most effective for use in automobile industry.

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