Design and Analysis of Core Chamber of Muffler

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Abstract: Over a few decades it is observed that the number of vehicles has increased due to which the level of noise emitted by vehicles has become worse. When the vehicle is in moving state then engine and exhaust system are one of the main constituents of pass-by-noise. The burnt gases from the engine are coming out at high pressure which has to be suppressed by exhaust system. Muffler can be used to reduce the sound levels. In this study geometrical optimization in terms of transmission loss has been done for simple expansion chamber muffler. Firstly, the diameter of chamber (D) to diameter of inlet tube (d) range has been selected from the literature survey. The simulations were conducted on the selected range the on the basis of maximum transmission loss using Ansys software. The maximum transmission loss was coming out when D/d equals to 4.38. Further, simulations were done for the length of chamber (L) to diameter of chamber (D) ratio within the range of 1.2 to 1.6. From the simulated results it is observed that the stable maximum transmission loss value was obtained for L/D of 1.6.The transmission loss values for L/D ratio of 1.3 are comparably good as of 1.6 L/D ratio.However due to size restrictions 1.3 L/D ratio is considered. Considering this proposed ratio an optimized muffler can be designed and manufactured within the specified geometric dimensions.

Keywords: Simple Expansion chamber, Muffler, Transmission loss, Noise reduction.

1. Introduction

Over the last two decades number of vehicles has increased, due to which the level of noise emitted by vehicles is getting worse. In this exhaust system produces noise almost ten times than that of structural noise. So special attention has been paid on exhaust system by using acoustic filters. Muffler is one such type of acoustic filter which plays an important role in reducing exhaust noise. That's why many researchers have selected muffler as their prime area of interest for research. In general, the inlet pressure and outlet pressure of muffler are taken into consideration because the mufflers performance parameters entirely depend on it. A vast number of simulation methods are available to design and check its performance virtually. In earlier years due to the lack of advancement in computer use and functions there has been limitations for predicting mufflers performance and its properties cannot be aligned with practical results sometimes. But with the invention of more sophisticated simulation software and solvers like Finite Element Method (FEM) and Computational Fluid Dynamics (CFD), it has become easy for predicting this muffler performance with great accuracy [1].

A muffler or silencer is an acoustic filter applied at exhaust system for reducing the emitted noise of an IC engine. In most internal combustion engines, compressors, air conditioning system etc. mufflers are installed within the exhaust system. The muffler is used as an acoustic soundproofing device for the reduction of the noise emitted by the exhaust system by way the way of acoustic quieting. In most internal combustion engines, compressors, air conditioning system etc. mufflers are installed within the exhaust system. The muffler is used as an acoustic soundproofing instrument for the noise reduction at the exhaust system by the way of acoustic quieting [1]. In automotive industry, reactive muffler or dissipative mufflers are normally used and they work at certain frequency spectrum. Reactive mufflers are favorable at low frequency ranges whereas dissipative are favorable for high frequency ranges about 1500-2000 Hz [9]. The science of acoustics of muffler and ducts is over 150 years old. Davis et.al in 1954 had done the first comprehensive experiment on the design and analysis of muffler. Davis et al. used the acoustic transfer matrix method and studied the noise reduction principle of muffler. Experimental verification is also performed and with respect to it muffler research theory is established [2]. In their report they had done experiment on 77 different single chamber and multiple chamber mufflers. From the experiment they have plotted the attenuation to frequency curve and this result were compared to the theoretical results. Later Fukuda et al. had developed the transfer matrix method

(TMM) which is ideally suited for acoustical modelling of cascaded element in automotive mufflers [3]. This strategy made the standing wave factors to move starting with one component then onto the next in course. The investigation of this work is performed through transfer matrix method. This method made the standing wave variables to move from one element to the next in cascade. It led to innovation of algebraic algorithm which help in rational synthesis of 1D acoustical filter and vibration isolator [4]. Different researchers have developed different filters with time and one such is the Helmholtz resonator. Munjal studied the Helmholtz resonator and in his work and it was found that Helmholtz resonator introduce a spark peak at its resonance frequency [5]. Sullivan and Crocker modelled a concentric tube resonator and use a 1D control volume approach and later he used a segmentation approach and configured a three interacting ducts [12]. A large research was carried out over the decade and acoustical analysis of complex perforated element and open-end flow reversal element was done. Automobile engine is a variable speed engine and a muffler should act as a low pass filter. Nakra et al. in his study has discussed about the combination of reactive muffler and absorptive muffler. They have studied on the noise attenuation characteristics. In their work theoretical predications are verified by experimental method and is found that combination muffler i.e. backflow in parallel combined muffler and absorptive type muffler gives high noise reduction over a wide frequency range as compared to other types of muffler [8]. Different researchers had used Finite Element Method (FEM) for dissipative muffler. Craggs used FEM and a locally reacted model to determine the behaviour of a lined expansion chamber through simulation method [11,13]. Kagawa et. Al. used temperature gradient and performed experimentation compared the FEM results of Craggs with their result for lined expansion chamber [10]. Snehasis worked on hybrid muffler which can be used for wide frequency range [4]. He had performed the acoustic analysis which shows how sound pressure changes inside the muffler. He had performed the transmission loss analysis and compared his result with the theoretical work of Lee [9]. Lee, initially worked on a simple expansion chamber where the acoustic behaviors are evaluated through analytical, computational and experimental method. Then for dissipative and reactive muffler the transmission loss in calculated. Finally, a combination of dissipative, reactive and Helmholtz resonator is used for constructing a hybrid muffler. Where analytical and experimental method is used for determining the transmission loss performance of the muffler over different frequency ranges. He used the mean flow effect and investigated the acoustic behaviour analytically, computationally and experimentally [9,16]. A simple expansion chamber consists of a chamber, an inlet and outlet tube. According to Potente (2005), larger expansion ratio gives larger value of transmission loss. According to his study length of chamber should be 1.5 times the diameter of chamber. He also said that size and weight of muffler are also main factors that should be considered while designing the muffler [6].

In this study firstly the simulations were done by varying the range of D/d from 3.36 to 4.38. The range was selected by referring the literature and simulations were carried out on ratios 3.36, 3.615, 3.87, 4.125 and 4.38 and transmission loss were calculated. The maximum transmission loss was obtained at the ratio of 4.38. Further, the L/D ratio was varied from 1.2 to 1.6 in five equal steps by keeping D/d ratio as 4.38. All the simulated results are shown along with valid arguments.

2. Performance Evaluation Parameter: Transmission Loss (TL)

It is used to characterize the acoustic behaviour of a silencer, since it is representative of the silencer itself, neither source or termination impedance is considered[15]. TL is also defined as the ratio of incident and transmitted power (L_{wi} and L_{wout}) of a silencer and it is an assumption of anechoic termination and plane-wave propagation inside upstream and downstream tubes by

$$TL = L_{wi} - L_{wout} = 10log\left|\frac{S_{in}{A_{in}}^2}{2}\,\frac{2}{S_{out}{A_{out}}^2}\right| \qquad (1)$$

Where Sin and Sout are the cross-sectional areas of the inlet and outlet ducts respectively and Ain and Aout are the magnitude of incident and transmitted planer waves[14]. When the inlet and outlet pipe ducts are same then the equation reduce to

$$TL = 20log\left|\frac{A_{in}}{A_{out}}\right| \quad (2)$$

The magnitude of incident and transmitted waves needed can be expressed in terms of reflection coefficients in terms of inlet and outlet surface of the silencer (Ra and Rb) as

$$A_{in} = \frac{p_{m2}}{1+Ra} \quad (3)$$

$$A_{out} = \frac{p_{m2}}{1+Rb} \quad (4)$$

TL is used to access the acoustic performance since it is independent of the input and termination impedance, i.e. representative of the silencer itself.

In case of Simple Expansion Chamber, the transmission loss is calculated as

$$\text{Transmission Loss (TL)} = 10\ \text{Log}_{10}\left[1+\frac{1}{4}\left(m-\frac{1}{m}\right)^2 sin^2 kL_c\right] \quad (5)$$

L_c is chamber length, D is chamber diameter, d is inlet tube diameter

wave number of sound (k) =2πf/c,

where f is frequency, and c is sonic speed

$$m = \frac{\frac{\pi}{4}D^2}{\frac{\pi}{4}d^2} = \frac{D^2}{d^2} \quad (6)$$

3. Research Methodology

In this study the work performed by Milad et. Al. and Lee et.al. are studied by simulation method and its performance results are compared with a new proposed simple expansion chamber design. The results obtained by simulation method for the new proposed design are validated by mathematical calculation.

4. Results and Discussion

4.1 Simple expansion chamber

For proposing the relations, consider the model of Milad et al.as shown on figure 1.

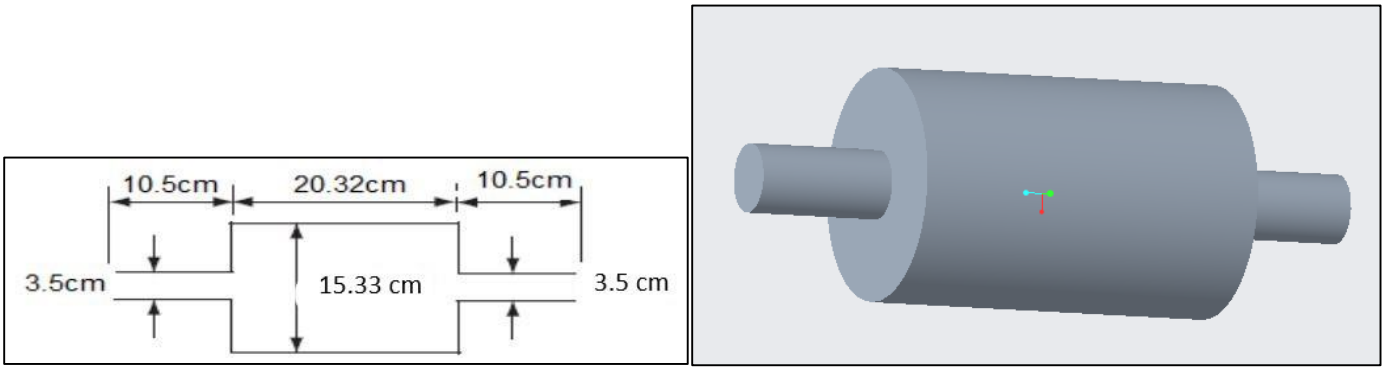


Figure 1 : Simple expansion chamber model of Milad et al.(2017)

From the figure we can say that

Length of expansion chamber = 1.33 x Diameter of expansion chamber

Diameter of expansion chamber = 4.38 x Diameter of inlet/ outlet tube

The experimental work performed by Seybert and Tao [7] for the figure 1 is shown in figure 2.

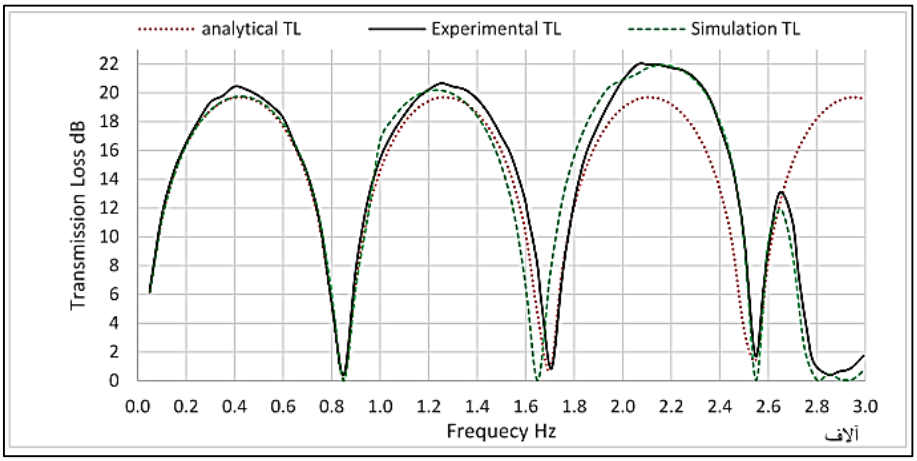


Figure 2: Work performed by Milad et al.

The transmission loss values for the figure 2 is shown in table 1 and the maximum TL is around 22 dB between frequency 2000 Hz – 2150 Hz.

Table 1: Measured experimental data by Seybert and Tao

Hz	TL	Hz	TL	Hz	TL	Hz	TL	Hz	TL	Hz	TL	Hz	TL	Hz	TL
50.0	6.3	450.0	20.2	850.0	0.4	1250.0	20.7	1613.3	11.1	1953.3	19.6	2360.0	19.6	2700.0	11.1
100.0	11.5	500.0	19.6	900.0	7.8	1300.0	20.4	1646.7	8.3	2000.0	20.9	2406.7	17.4	2726.7	7.2
150.0	14.6	550.0	19.1	950.0	12.6	1350.0	20.2	1666.7	5.2	2060.0	22.0	2453.3	14.8	2760.0	3.5
200.0	16.5	600.0	18.3	1000.0	15.4	1400.0	19.6	1706.7	0.9	2106.7	22.0	2500.0	10.0	2786.7	1.3
250.0	18.0	650.0	16.3	1050.0	17.2	1450.0	18.5	1753.3	7.6	2146.7	22.0	2546.7	1.7	2846.7	0.4
300.0	19.3	700.0	14.3	1100.0	18.5	1500.0	17.0	1800.0	12.4	2200.0	21.7	2580.0	6.3	2893.3	0.7
350.0	19.8	750.0	11.1	1150.0	19.6	1540.0	15.7	1846.7	15.7	2253.3	21.5	2600.0	9.1	2940.0	0.9
400.0	20.4	800.0	5.4	1200.0	20.2	1593.3	12.8	1906.7	18.0	2306.7	20.9	2646.7	13.0	2993.3	1.7

The work performed by Milad et al. is now performed in simulation software and the results found are shown in table 2 and figure 3.

Table 2: Transmission loss values from simulation software

Tabular Data

	Frequency [Hz]	Transmission Loss [dB]		Frequency [Hz]	Transmission Loss [dB]		Frequency [Hz]	Transmission Loss [dB]
1	50.	6.133	21	1050.	16.639	41	2050.	21.114
2	100.	11.141	22	1100.	18.1	42	2100.	21.583
3	150.	14.233	23	1150.	19.107	43	2150.	21.781
4	200.	16.314	24	1200.	19.75	44	2200.	21.714
5	250.	17.76	25	1250.	20.077	45	2250.	21.363
6	300.	18.747	26	1300.	20.108	46	2300.	20.685
7	350.	19.369	27	1350.	19.843	47	2350.	19.584
8	400.	19.673	28	1400.	19.259	48	2400.	17.86
9	450.	19.68	29	1450.	18.309	49	2450.	15.042
10	500.	19.389	30	1500.	16.894	50	2500.	9.7298
11	550.	18.78	31	1550.	14.83	51	2550.	0.
12	600.	17.803	32	1600.	11.712	52	2600.	9.3676
13	650.	16.365	33	1650.	6.5014	53	2650.	11.761
14	700.	14.285	34	1700.	7.8078e-003	54	2700.	8.7167
15	750.	11.175	35	1750.	7.2231	55	2750.	2.192
16	800.	6.0921	36	1800.	12.35	56	2800.	1.0074e-002
17	850.	2.8958e-003	37	1850.	15.519	57	2850.	0.38481
18	900.	6.455	38	1900.	17.689	58	2900.	1.3721e-002
19	950.	11.454	39	1950.	19.24	59	2950.	5.3264e-002
20	1000.	14.548	40	2000.	20.35	60	3000.	0.7307

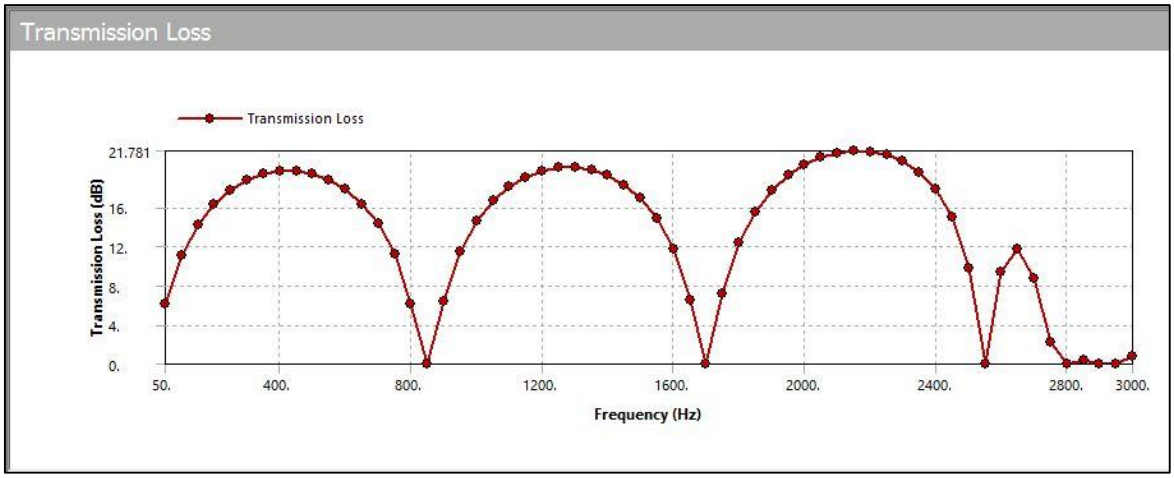


Figure 3 : Transmission loss curve from simulation software for the model of Milad et al.

From the experimental and simulated result, it is found that the TL is almost same at all frequencies and the maximum transmission loss value is about 21.78 dB.

4.2 Dimension Modification: The length and diameter of the chamber are now modified for this model i.e. the work of Milad et al.

Different assumed conditions

Case I: Length of expansion chamber (Lc) = 1.2 x Diameter of expansion chamber (Dc)

Case II: Length of expansion chamber (Lc) = 1.3 x Diameter of expansion chamber (Dc)

Case III: Length of expansion chamber (Lc) = 1.4 x Diameter of expansion chamber (Dc)

Case IV: Length of expansion chamber (Lc)= 1.5 x Diameter of expansion chamber (Dc)

Case V: Length of expansion chamber (Lc)= 1.6 x Diameter of expansion chamber (Dc)

Diameter of inlet or outlet tube (Di) = Diameter of expansion chamber (Dc) / 4.38

The Transmission Loss is now evaluated for all the different cases shown in table 3 and the results obtained are shown in table 4.

Table 3 : Dimension of different models

S. No.			CASE 1	CASE 2	CASE 3	CASE 4	CASE 5
	Dc (cm)	Di(cm)	Lc (cm)	Lc (cm)	Lc (cm)	Lc (cm)	Lc (cm)
1	15	3.42	18	19.5	21	22.5	24
2	15.25	3.48	18.3	19.825	21.35	22.875	24.4
3	15.5	3.54	18.6	20.15	21.7	23.25	24.8
4	15.75	3.60	18.9	20.475	22.05	23.625	25.2
5	16	3.65	19.2	20.8	22.4	24	25.6
6	16.25	3.71	19.5	21.125	22.75	24.375	26
7	16.5	3.77	19.8	21.45	23.1	24.75	26.4

The transmission loss performance parameter is evaluated for these conditions by using ANSYS.

Table 4 : Transmission Loss for different dimension mufflers evaluated by simulation software

S. No.			CASE 1	CASE 2	CASE 3	CASE 4	CASE 5
	Dc (cm)	Di(cm)	Transmission Loss				
1	15	3.42	47.944	22.051	21.282	21.357	22.584
2	15.25	3.48	58.44	22.029	21.289	21.356	22.562
3	15.5	3.54	41.811	22.055	21.287	21.358	22.439
4	15.75	3.60	37.106	22.046	21.278	21.317	22.457
5	16	3.65	35.185	22.041	21.317	21.261	22.601
6	16.25	3.71	42.483	22.051	21.286	21.35	22.545
7	16.5	3.77	46.474	22.045	21.29	21.353	22.604

From table 4 it is found that decreasing the L/D ratio to 1.3 gives us high transmission loss value. But further decreasing it will give us drastic change in the acoustic performance value which will affect the efficiency of muffler. The transmission loss value is high for Case 5 but due to our restrictions in dimensions the transmission loss value for this case is not considered.

4.3 New Expression

From the different analysis and results shown in table 4 and table 6, below mentioned relations could be considered as the standard relation for designing a simple expansion muffler.

Length of chamber = 1.3 x Diameter of chamber (5)

Diameter of inlet or outlet tube (Di) = Diameter of expansion chamber (Dc) / 4.38 (6)

Equation 5 and equation 6 are considered as the standard relation for designing a muffler.

4.4 New Proposed design for Simple Expansion Chamber

In this study equation 5 and equation 6 is used for designing a simple expansion chamber muffler. The dimension taken are shown in figure 4. The diameter of the chamber, length of chamber and the diameter of the inlet / outlet tube are 15.5 cm, 20.15 cm and 3.54 cm respectively.

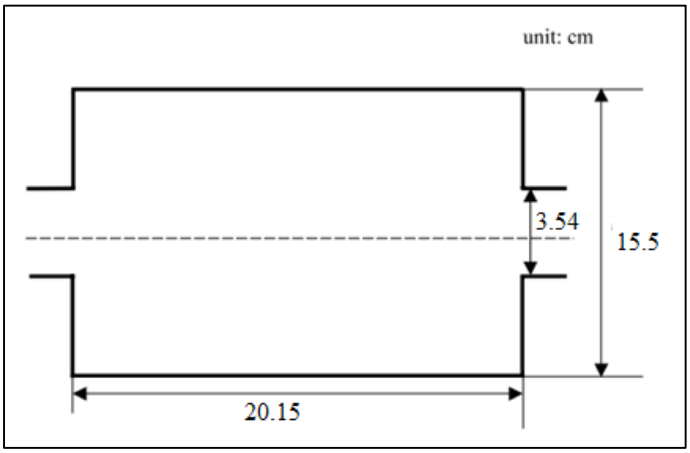


Figure 4: Simple Expansion Chamber

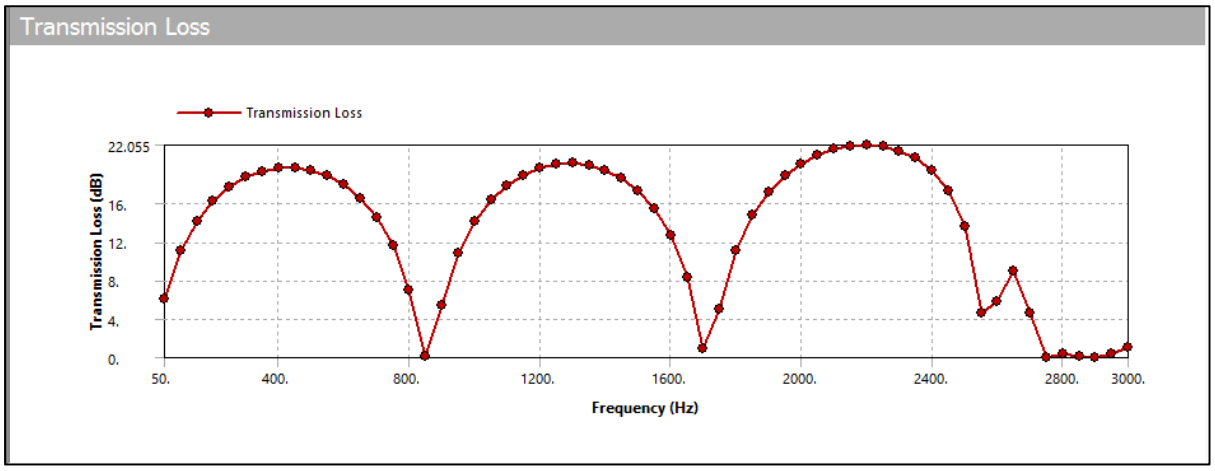


Figure 5: Transmission loss curve for Simple expansion chamber

The predicted transmission loss from the 1D-plane wave simulation approach is shown in figure 5. It shows the maximum transmission loss in the high frequency range and it about 22.06 dB.

Mathematical Calculation

Considering the new proposed design, the performance parameter is evaluated through mathematical formula of muffler. The performance parameter i.e. transmission loss is calculated at two frequencies 400 Hz and 1200 Hz respectively.

$$m = \frac{\frac{\pi}{4}D^2}{\frac{\pi}{4}d^2} = \frac{D^2}{d^2} = \frac{15.5^2}{3.54^2} = 19.17$$

- *At f = 400 Hz,* $k = \frac{2\pi f}{c} = \frac{2\pi 400}{343} = 7.327$

$$TL = 10\,Log_{10}\left[1 + \frac{1}{4}\left(19.17 - \frac{1}{19.17}\right)^2 sin^2(7.327 \times 0.2015)\right] = 19.617\,dB$$

- *At f = 1200 Hz,* $k = \frac{2\pi f}{c} = \frac{2\pi 1200}{343} = 21.982$

$$TL = 10\,Log_{10}\left[1 + \frac{1}{4}\left(19.17 - \frac{1}{19.17}\right)^2 sin^2(21.982 \times 0.2015)\right] = 19.31\,dB$$

From the simulation method and mathematical method, it is found that for the proposed design the transmission loss (TL) value is almost same with respect to the frequencies.

Frequency (Hz)	TL from simulation method (dB)	TL from mathematical method (dB)
400	19.658	19.617
1200	19.657	19.31

5. Conclusion

Considering the transmission loss as the main acoustic performance parameter, acoustic analysis is performed for different cases. It was observed that there was a drastic increase in transmission loss value for case 1 conditions which is not acceptable as it would lead to decrease in efficiency of engine. Further, it was observed that the transmission loss value is highest in case 5. But from literature the size for muffler was restricted to length of 21.5 cm, so the transmission loss value at L/D ratio of 1.3 i.e case 2 is considered. An increase of 3.2 to 3.5 % transmission loss value is observed in case 2 than that of case 3 and case 4. Thus, an optimized simple expansion chamber muffler is designed and constructed by considering the L/D ratio of 1.3 and maximum transmission loss is found be 22.055 dB. So,this optimized simple expansion muffler could also be used as in vehicle as one of the mufflers for reducing the exhaust noise.

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