Effect of Change in Diameter on Muffler Transmission loss using COMSOL

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Abstract : *Muffler analysis is always challenging task due to complex design, shape and size limitation for specific application. In this paper the inlet diameter of muffler is varied for comparison. Two finite element methods (FEM) Results are compared using COMSOL 5.0 software. Two different muffler configurations are considered, representing the effects of adding absorptive lining and without absorptive lining to increase the transmission loss (TL), from computational analysis it is observed that for 40 mm inlet transmission loss is more compared with 30 mm inlet diameter.*

Keywords – *Transmission loss (TL), Acoustic liners,*

I.   INTRODUCTION

Mufflers are normally used to reduce exhaust noise of engine. The acoustical design of such muffler is challenging task for designer. The efficient design demand and its performance as per application forced engineers for development of various acoustic elements within muffler, like sudden change in area, rigid baffles, area discontinuities, different density absorptive liner and pipes with perforation and so on. However, sometimes these elements also lead to pressure drop in the flow. To overcome this drawback, absorptive liner with various combination of area discontinuities are used in muffler design.The TL behavior is analyzed by D. Denia et. al. [1] 2D axisymmetric analytical approach used for two-chamber muffler. Few effects were studied, including rigid baffle inside chamber, its radius & position along axial direction with and extended inlet/outlet. S. Bilawchuk et. al. [2] The increased use of large industrial machinery and specific application silencer design, to minimize design time it would be helpful to have means to predict the TL characteristics before design. The prototype derivation based on mode matching techniques. For higher order modes R. Glav et. al. [3] presented for 2-port matrix for a folded resonator with neglecting flow interaction effects. The improved method solved Helmholtz's equation with FEM. Renato Barbieri et. al. [4] use shape design combine Zoutendijk's method and FEM. To control the pollution error quadratic triangular meshes are constructed and solved using Zoutendijk's feasible directions method, for constrained and unconstrained shape optimization studied. Min-Chie Chiu [5] worked on multi-chamber shape optimization without considering back pressure. Key Fonseca de Lima,[6-7] evaluated and validated appropriate size of inlet & outlet duct by Parametric optimization. To study complex mufflers an Integrated TMM has developed & validated up to the cut-off frequency comparisons with 3D FEM results, by changing internal configuration The TL characteristic can be altered. Xiang Yu et. al. [8] provided some guidelines for system optimization by studying effect of several configurations. Xiang Yu et. al. [9-12] presented a theoretical description of the overall TL for cascade-connected multiple sub-chambers to achieved desired attenuation performance. V. Ovidiu [10] considered two special cases of reactive silencer investigated acoustic performance using numerical and experimental techniques. Jin Woo Lee et. al. [11] Studied & validated topology-optimization for a smaller volume of partition than the previous one
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II.   TYPES OF MUFFLERS

2.1 Reactive Type Muffler

It reduces the noise by using phenomena of destructive interference. Reflections occur when there is a change in geometry or an area discontinuity with the help of perforations in the pipes inside the muffler. Sound pulses are scatter out by offset inlet and outlet tube with perforations in all directions within muffler creates destructive interference. Sub-chambers and sudden changes in geometry they reduce noise at different frequencies due to that the exhaust gasses moved towards outlet, few configurations joined to create impedance mismatch.

2.2 Absorptive Type Muffler

Absorptive material converts Energy of sound waves into heat. It consists of perforated pipe within steel housing. Absorptive material lined in chamber which minimizes back pressure than reactive muffler. Absorptive mufflers create less back pressure than reactive mufflers.

III. THEROTICAL ANALYSIS OF MODEL

Pressure acoustic used to solve this problem in frequency domain. The equation is a modified Helmholtz equation for the acoustic pressure p

$$\nabla.\left(-\frac{\nabla p}{\rho}\right)-\frac{\omega^2 p}{c^2 \rho}=0 \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where ω is angular frequency, ρ material density and c is the sound speed. In the absorbing glass wool, for Poroacoustics domain, $c_c = \omega/kc$, and a complex density, $\rho_c = k_c Z_c/\omega$, where k_c is the wave number and Z_c is the impedance. This is a so-called porous domain equivalent fluid model. For a highly porous material, Delany and Bazley equation parameters are used.

$$k_c = k_a\left(1+0.098\times\left(\frac{\rho_a f}{R_f}\right)^{-0.7}-i\times 0.189\times\left(\frac{\rho_a f}{R_f}\right)^{-0.595}\right) \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$Z_c = Z_a\left(1+0.057\times\left(\frac{\rho_a f}{R_f}\right)^{0.374}-i\times 0.189\times\left(\frac{\rho_a f}{R_f}\right)^{-0.732}\right) \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where R_f is the flow resistivity, and where $k_a = \omega/c_a$ and $Z_a = \rho_a c_a$. The attenuation is defined as the ratio between the incoming and outgoing acoustic energy.

$$TL = 10 Log\left(\frac{P_{in}}{P_{out}}\right) \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Here P_{in} is incoming power at the inlet & P_{out} is the outgoing power at the outlet. Assuming plane wave propagation we can calculate TL as an integral over the respective inlet and outlet surface. The frequency above which all the frequencies are suppressed by the muffler is called cut-off frequency. This can achieve by using a Low & High pass filter.

$$P_{in} = \int_{\partial\Omega}\frac{p_0^{\;2}}{2\rho c}dA \quad \text{and} \quad P_{out} = \int_{\partial\Omega}\frac{|p|^2}{2\rho c}dA$$

IV. COMPUTATIONAL ANALYSIS & STEPS INVOLVED

4.1 COMSOL Multiphysics Module
This module contain many sub-module, we solve this problems in the Pressure acoustics module. The physics interfaces play a vital role to couple with other physics interface in COMSOL.

4.2 Parameter Required for Simulation
Table 1 List of Parameters required for simulation

Name	Value	Description
p0	1[Pa]	Amplitude of incoming pressure wave
rho_ap	12[kg/m³]	Apparent density of glass wool
d_av	10[um]	Mean fiber diameter
R_f	1424.2 kg/(m³·s)	Flow resistivity

4.3 Boundary Conditions
Three boundary conditions are used to all problems.
• Hard wall boundary where velocity is zero.
• At the inlet combination of incoming and outgoing plane waves.
• At the outlet radiation condition for an outgoing plane wave.

4.4 Meshing the Model

The wavelength λ value depends on the sound speed and frequency ($\lambda = c / f$). Meshing resolve this wavelength. Isotropic meshing used with twelve DOFs per wavelength.
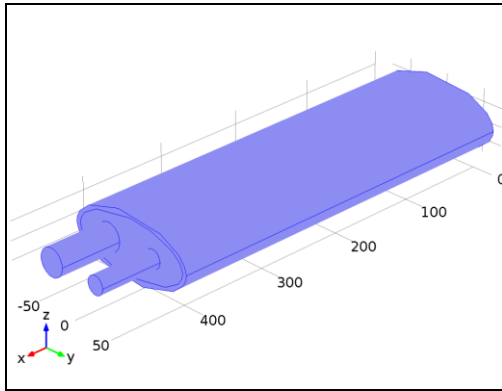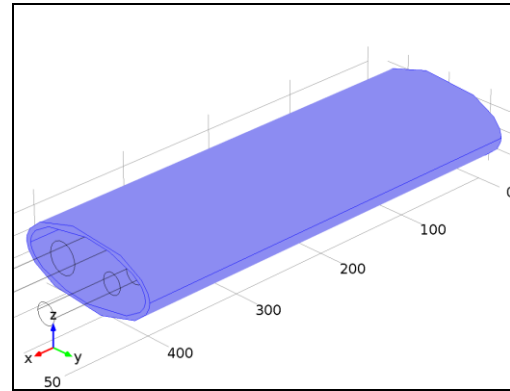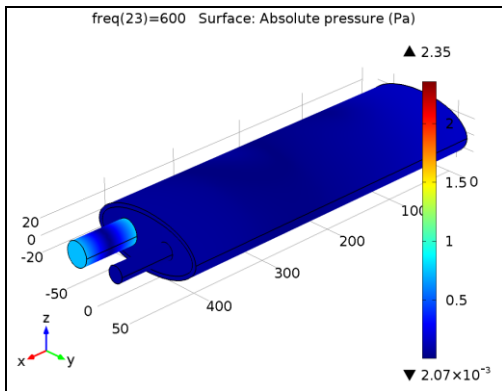

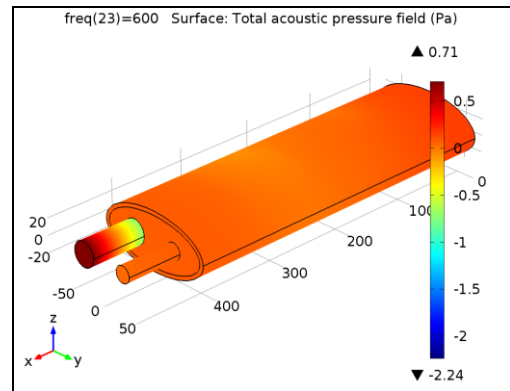| **Fig. 2 a) without liner 30mm inlet** | **Fig.2 b) With Absorptive liner 30mm inlet** |

Fig. 2 a) shows complete muffler used for simulation with absorptive liner of Glass-wool and Fig. 2 b) shows only the Absorptive liner separately.

4.5 Result of COMSOL 5.0

The pressure distribution in the absorptive muffler with and without the lining material is shown in Fig.3 a) & b) for the frequency f = 600 Hz. From the figure it is seen that at this frequency not only longitudinal standing waves exist. The behavior shows complicated and unpredictable damping properties for higher frequencies, while glass-wool improves TL at the resonance frequencies as well as at higher frequencies.

(a) **(b)**

Fig. 3 Absolute pressure level a) without liner b) With Absorptive liner for 30mm inlet

Fig. 3 a) shows absolute pressure level of muffler at frequency of 600Hz for 30mm inlet pipe diameter. The absolute pressure value for 30 mm inlet without liner is 2.35 Pa while with Acoustic liner it is 0.71Pa.Fig. 4 a) shows sound pressure level of muffler at frequency of 600Hz for 30mm inlet pipe diameter, and it is same as we are giving constant sound pressure as input which is 1 Pa.
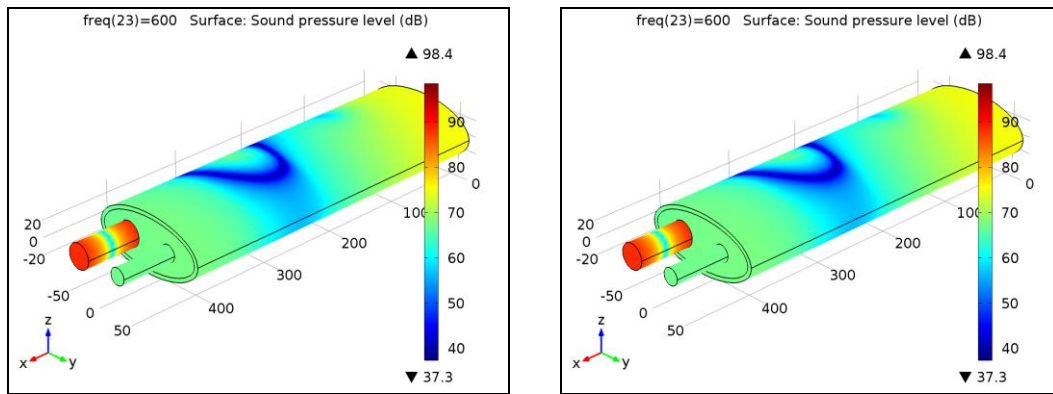
(a)   **(b)**

Fig. 4 Sound pressure level a) without liner b) With Absorptive liner 30mm inlet

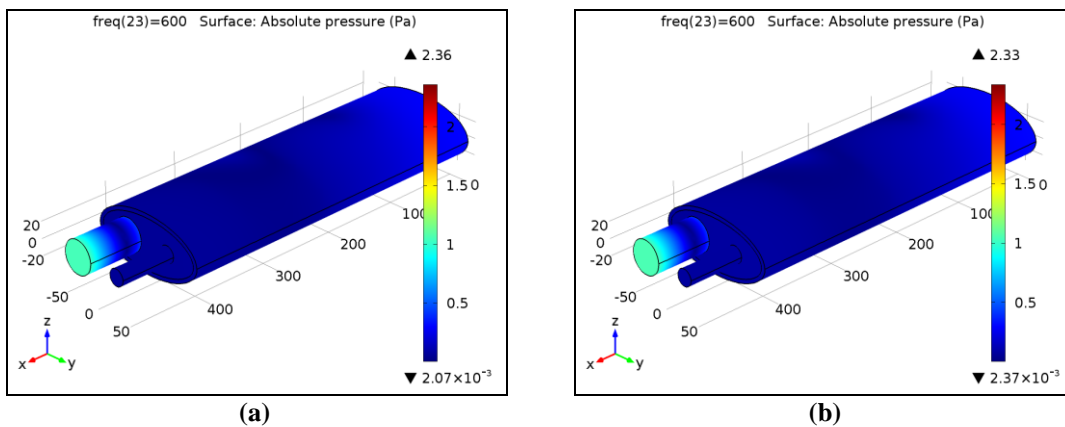**(a)**   **(b)**

Fig. 5 Absolute pressure level a) without liner b) With Absorptive liner for 40mm inlet

Fig. 5 a) shows absolute pressure level of muffler at frequency of 600Hz for 40mm inlet pipe diameter. The absolute pressure value for 40 mm inlet without liner is 2.35 Pa while with Acoustic liner it is 2.33Pa.
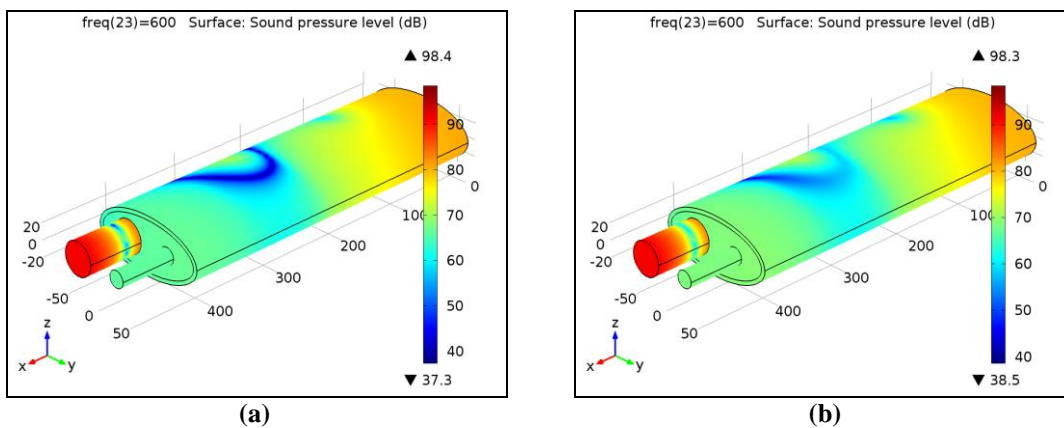

(a)   **(b)**

Fig. 6 Sound pressure level a) without liner b) With Absorptive liner 30mm inlet

Fig. 6 a) shows sound pressure level of muffler at frequency of 600Hz for 30mm inlet pipe diameter, and it is nearly same as we are giving constant sound pressure as input which is 1 Pa. Fig. 7 a) shows plot of frequency (Hz) vs. Transmission loss (dB) of muffler for 30mm inlet pipe diameter, maximum TL is 42 dB observed at 400 Hz frequency. b) Shows maximum TL is 52 dB observed at 450 Hz frequency.
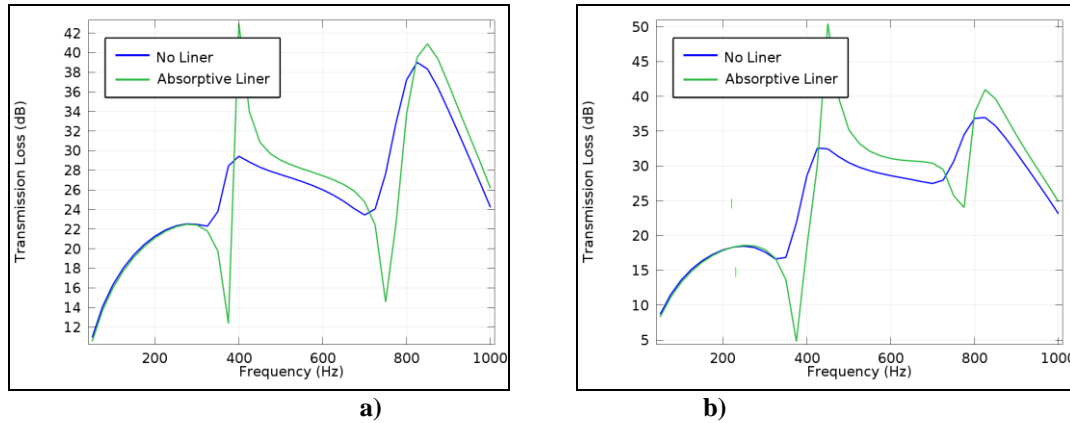
Fig. 7 a) TL by COMSOL without liner and With Absorptive liner for 30mm inlet b) for 40mm inlet
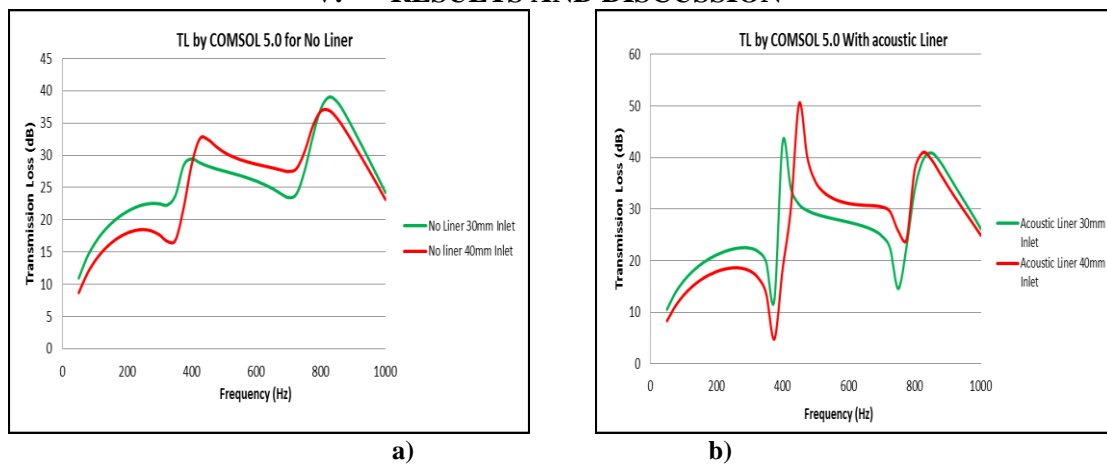
V. RESULTS AND DISCUSSION

Fig. 8 a) TL Comparison of COMSOL for 30 & 40 mm inlet a) No liner b) With Acoustic liner

Fig. 8 shows graphs of transmission losses across a range of frequency. Fig 8 a) it is observed that on a frequency value of 800-850 Hz we get maximum attenuation of 39dB for 30 mm inlet diameter and 36 dB for 40 mm inlet for without liner condition. Fig 8 b) frequency value of 400-450 Hz we get maximum attenuation of 42dB for 30 mm inlet diameter and 50 dB for 40 mm inlet for with Acoustic liner condition. We can clearly see that for larger diameter of inlet manifold we get maximum transmission loss.

VI. CONCLUSION

Fig. 7 a) is FEM output of muffler for 30 mm inlet diameter and fig. 7 b) is FEM output of muffler for 40 mm inlet diameter. In fig. 8 a) is TL plot without absorptive liner for 30mm (Green line) inlet and 40mm inlet(Red Line) for this condition TL is more for 40mm inlet. In fig. 8 b) is TL plot with absorptive liner for 30mm (Green line) inlet and 40mm inlet(Red Line) for this condition TL is more for 40mm inlet. We can also conclude that if we increase the diameter of inlet manifold we get increased transmission loss.

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