Experimental Investigation of Thickness Influencing Acoustic Performance of Sound Absorbing Material

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Abstract

Characteristics of the porous medium in the muffler attenuation are a complex science. Attenuation problem not only lies in fibrous material but also to muffler space and its configuration. Using this conception of thin fibers, the best material is chosen to effectively utilize in the most economic way of sound reduction. The merit of this investigation lies in the experimental test conducted to identify the acoustic performance of various sound absorbing fibrous material influencing physical properties particularly thickness in exhaust muffler.

Keywords: *Fiber Material, Thickness, Acoustic Performance, Exhaust muffler.*

1. Introduction

Exhaust noise can be attenuated in several ways. A distinction is generally made between active and passive attenuation, although purely active mufflers are not yet ready for production in series. For this reason, modern exhaust system consists of one or more passive reflection or absorption mufflers. Reflection muffler attenuates the sound by reflection and interference; absorption mufflers dissipate the acoustic energy into heat energy through the use of porous material as glass wool.

The absorptive muffler consists of a perforated pipe covered by noise absorbing glass wool as shown in figure 1 & 2. The tube is perforated so that some part of the pressure wave goes through the perforation through the noise absorbing glass wool. The glass wool is a noise dampening material which is fibrous in nature and is protected from the surrounding by an auxiliary cover made of a steel metal sheet. The glass wool can with stand heat more than 950ºC thus it is suitable for exhaust application with high temperature [1].The absorption muffler as the name suggests absorbs the noise through its fibrous glass wool where the noises dissipate as heat due to the friction. The heat then transfers to the outer shell and loses its intensity thus reducing the noises of the exhaust. The absorption muffler generally consists of straight through pipes so the exhaust gases will have minimal restriction inside the pipe creating very less back pressure compared to reflective muffler. But the straight through absorption muffler are effective only in higher frequencies i.e. in the range of above 600Hz and above. This muffler works well in higher engine rpm with higher frequency and its harmonics [2]. Below 600Hz the noise reduction performance gradually reduces in absorption muffler. The amount of glass wool is selected based on the size of the outer shell where its dimensions are solely selected due to the under body space of the vehicles chassis. The glass wool quantity is basically selected by its packing density a good muffler with greater noise performance will have a packing density between 80 to 120kg//m3. The performance of the muffler reduces if the packing density is below 80kg//m3 and there will be no improvement in absorption quality if it is above 120kg/m3.The perforation size in the pipe should not be above 3mm diameter because the fibrous glass wool may escape through the holes to the atmosphere by the high velocity gas flow through the pipe leading to reducing in mufflers noise attenuating performance. A disadvantage in using absorption muffler is the glass wool may deteriorate due to heat in the longer run.

Absorptive materials are generally resistive in nature, either fibrous, porous or in rather special cases reactive resonators Lewis H. Bell, [3] Classic examples of resistive material are nonwovens, fibrous glass, mineral wools, felt and foams Porous materials used for noise control are generally categorized as fibrous medium or porous foam. Fibrous media usually consists of glass, rock wool or polyester fibers and have high acoustic absorption. Sometimes fire resistant fibers are also used in making acoustical products Claudio, [4]. An absorber, when backed by a barrier, reduces the energy in a sound wave by converting the mechanical motion of the air particles into low-grade heat. This action prevents a buildup of sound in enclosed spaces and reduces the strength of reflected noise Lewis H. Bell., [3].

This paper describes the effect of the thickness of absorptive material and spacing plays an important role in sound attenuation for muffler. The attenuation increases sharply at high frequencies as the spacing is narrowed.

2. Factors Influencing Sound Absorption

Studies on various parameters that influence the sound absorption properties of fibrous materials have been bring out widely in this paper [5]. The studies are given below.

- Fiber Size

- Air flow resistance
- Porosity
- Tortuosity
- Thickness
- Density
- Compression
- Surface Impedance
- Placement/position of sound absorptive

3. Specimen Description

Seven randomly selected samples of fibrous materials have been investigated in a glass wool chamber of volume 2.6liter. Each sample weighing 271g is tightly filled with 104kg/m^3 of packing density. Figure 3 shows the tested fibrous materials. Sample A (E glass wool) is the most commonly used fiber glass wool in exhaust muffler because of its high heat resistive capacity. It can withstand temperature upto 650ºC. Sample B & C (super wool bulk and plus) are the materials with lightweight micro fibers with minimum and maximum service temperature respectively. Sample D (Rock wool) consist of recycled mineral fibers. It consists of blown plastic fibers and has a higher loft and smaller fiber diameters. Sample E (resin bonded wool) are common sound absorbing materials used to absorb aero caustics noise. Sample F represents loose wool with needle punched blends of fiber.

Fig 1: Different fibrous material used

4. Performance of Sound Absorbing Materials

For porous and fibrous materials, acoustic performance is defined by a set of experimentally determined constants namely: sound absorption coefficient, transmission loss and tail-pipe noise. There are different methods available to determine these acoustical parameters but all of these methods mainly involve exposing materials to known sound fields and measuring the effect of their presence on the sound field**.** Pressure drop test were also conducted with all different fibrous material.

5. Experimental Work

5.1 Measurement of Thickness

Thickness of the six fibrous samples is measured using axioscope. The instrument has a magnification of 1500X. The thickness of each sample is measured with 100X. Five values for each sample were taken and its average was calculated. Thickness report for each sample is shown below in table 1. From table 1 it is clear that sample D has the least thickness value following sample A & F has the highest thickness value**.**

Table 1: Thickness report measured from axioscope

Sample	Thickness (mm)	Service Temp (°C)
A	0.0220	650
B	0.0052	200
C	0.0063	1100
D	0.0024	700
E	0.0094	400
F	0.0200	500

5.2 Measurement of Sound absorption coefficient

Sound Absorption Coefficient is the measure of how much sound is absorbed by a material. The experimental setup is similar to that of transmission loss setup instead of muffler glass wool weighing 100g are placed which then closed by an adapter at the end. The absorption coefficient can be expressed as:

$$\alpha = 1 - \frac{I_R}{I_I}$$

Where α is the Sound Absorption Coefficient, I_R is the Reflected Sound Intensity and I_I is the Incident Sound Intensity. Referring to the above equation, it can be seen that the sound absorption coefficient, α of materials are varies in the range of 0 to 1. Value 0 indicates zero sound absorption while value 1 indicates perfect sound absorption. In the case of α = 0, the sound is completely deflected by the material. On the other hand, α = 1 represents that the sound is completely absorbed by the material.

- Absorptive material is tested by inserting each sample at 25mm into the sample holder, these sample holders are then attached to impedance tube.
- The sound absorption testing is based on the two-microphone method to transfer function.

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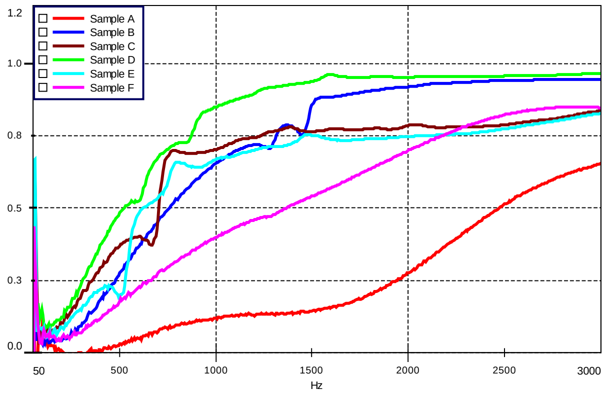

Fig 2. Comparison of sound absorption coefficient for different fibrous wool

- Absorption coefficient for six different samples is plotted as a function of frequency.
- The acoustic behavior of sound absorption coefficient measured varies for each material.
- Form the figure 2, it is seen that sample D with minimum thickness has the highest sound absorption coefficient.

5.3 Measurement of Transmission loss

Transmission loss is the rate of sound pressure level incoming and outgoing from the muffler. It was expressed on frequency domain. Transmission loss is independent from the source and depends on the structure of the muffler. Equipments used for measuring transmission loss are:

- Acoustic Driver
- 1/2 microphone A&B
- 1/2 microphone C&D
- Adapter and connection pipes
- Sound source
- Muffler Element

In the experimental set up, white noise signal produced by analyzer is transmitted to the source of the sound in order to generate the needed sound by amplifier. White noise which is generated by source is sent to the muffler. With two microphones that are placed in inlet and outlet of the muffler, sound pressure signals are collected during a period of time and these signals are converted to frequency domain with FFT after being amplified, and as a result auto-spectrum and cross-spectrum values are obtained. These data taken from the analyzer is processed by the computer and the transmission loss curves are obtained.

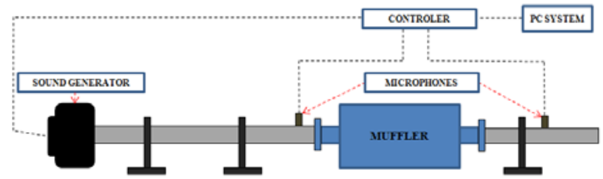

Fig 3: Experimental setup for measuring transmission loss

- A simple absorptive chamber of dimension 101mm diameter and 300mm length is used for the experiment.
- The sound absorption testing is based on the two-microphone method to transfer function.
- The TL behavior of an expansion chamber with a large diameter is investigated, as shown in figure 4.

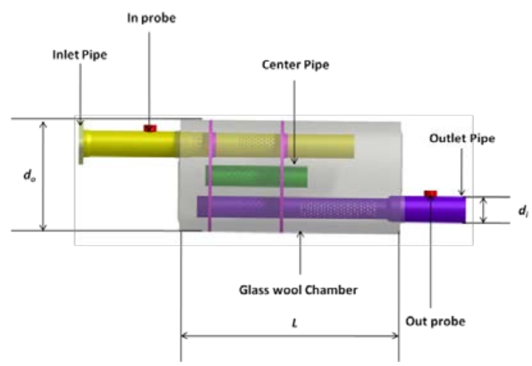

Fig 4. Expansion chamber dimensions (di = 0.043m, do = 0.101 m, l = 0.343m)

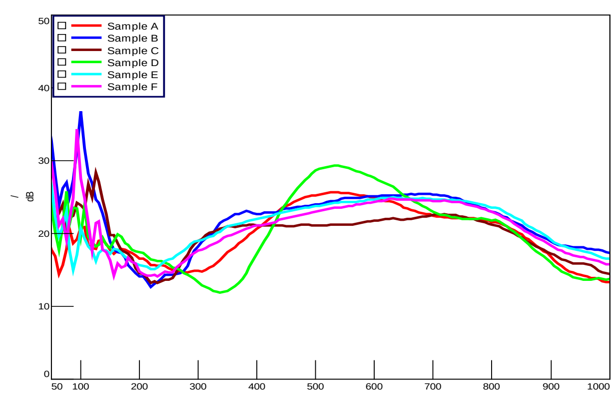

Fig 5. Comparison of TL measurement for different fibrous wool

Transmission loss measurement for seven samples is shown in figure 5. From the plot it is seen that sample D with minimum fiber thickness value has maximum transmission loss at frequency range of 300 to 750Hz.

5.4 Measurement of Tail -pipe Noise

The experimental setup of tail-pipe noise measurement system is shown in figure 5. The entire muffler assembly is insulated in a room called anechoic chamber designed completely to absorb reflections of either sound or electromagnetic waves. It is also insulated from exterior sources of noise. The combination of both cold flow and anechoic means they simulate a quiet open space of finite dimension, which is useful in measuring accurate noise results, else exterior influences would otherwise give false results.

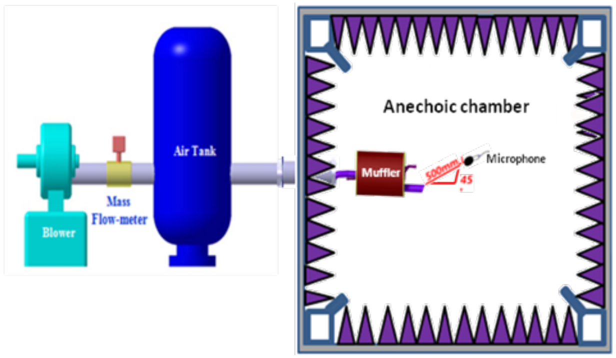

Fig 6. Experimental setup for measuring Tail-pipe noise

- Noise at the tail pipe is analyzed with the aid of microphones positioned at an angle of 45º and placed 500mm far from outlet pipe.
- Mass flow rate is increased from 50 to 340kg/h & the measurements are acquired for two minutes time span at all stages.

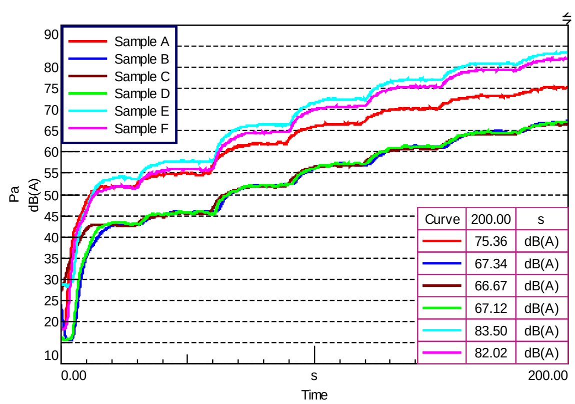

Fig 7. Comparison of Tail-pipe noise measurement for different fibrous wool

Tail pipe noise measurement for seven samples is shown in figure 7. From the plot it is seen that sample D with minimum fiber thickness has the least tail pipe noise of 67.12dB.

5.5 Measurement of Backpressure

The backpressure usually refers to the pressure exerted on a moving fluid by obstructions against its direction of flow. The average pressure in the exhaust pipe during the exhaust stroke is called the mean exhaust pressure and the atmospheric pressure is called the ambient pressure. The difference between these two pressures is defined as backpressure. The cold flow bench is used to measure the back pressure of muffler assembly with six different glass wools.

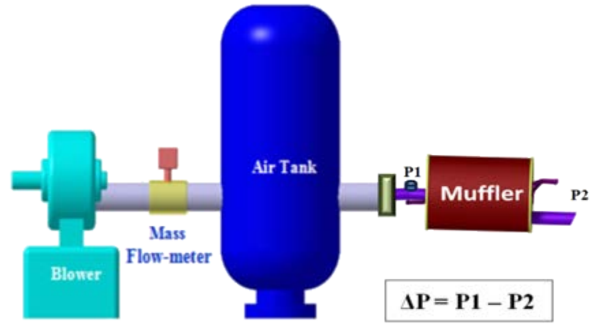

Fig 8. Experimental setup for measuring Backpressure

- Backpressure across the system is analyzed with the aid of two pressure sensors. Pressure sensor one (P1) is placed 50mm before muffler assembly, and pressure sensor two is placed open to the atmospheric pressure (P2).
- Mass flow rate is increased from 50 to 340kg/h & the measurements are acquired for two minutes time span at all stages.

The experimental results from cold flow bench for backpressure measurements are shown in Table 3.

Table 2: Backpressure measurement for different glass wool

S. No	Sample Description	Back Pressure (mbar)
1	Sample - A	39.6
2	Sample - B	41.9
3	Sample - C	38.4
4	Sample - D	40.8
5	Sample - E	40.7
6	Sample - F	41

From the plot it is seen that all samples have least and almost equal back pressure. Results shows backpressure effect is not much with the varying fibrous thickness.

6. Result Comparison

Table 3: Acoustic performance of different test compared with thickness value

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Sample	Thickness (mm)	TL (dB)	Sound Absorption Coefficient	Tail pipe noise (dB)	Back Pressure (mbar)
A	0.0220	74.12	0.77	82.02	39.6
B	0.0052	69.32	0.89	75.36	41.9
C	0.0063	70.28	0.82	67.35	38.4
D	0.0024	67.61	0.90	65.43	40.8
E	0.0094	74.81	0.85	66.67	40.7
F	0.0200	73.06	0.86	67.34	41

7. Conclusion

On comparing various experimental results, it is found that sound absorption property is more effective for sample D, fiber having reduced thickness. This is because, thin fibers allocate more pores on the surface of fibrous material allowing more sound waves to pass and get damped by friction.

This study will help us to select optimum sound absorbing material which attenuates wide range of high frequencies with less back pressure for muffler.

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