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Development of Impedance Tube to Measure Sound Absorption Coefficient

S. S. Bhattacharya, D. V. Bihola,

***Abstract:** An acoustic property of textile material can be measured using an impedance tube, is the most popular technique to measure normal sound absorption and transmission loss. This method consuming less time and a very small sample is required to assess the acoustic properties of the materials. Unfortunately, the cost of the impedance tube and software used for measurement is very high. This paper gives information about how to develop a cost-effective impedance tube suitable for researchers. The design, development, and fabrication of the impedance tube suitable for different frequencies with technical details are present here. Information related to some software which can be used to measure sound absorption coefficient also provided. To validate the testing results obtained from custom-build impedance tube, same samples were tested on commercially available impedance tube at PSG College, Coimbatore. It was observed that both the instruments provide almost same results, no statistically significant difference found in results. Base on the results design of customized impedance tube recommends to student and researcher interested in measuring acoustic properties of textile material.*

***Keywords:** Acoustic, Impedance tube, sound absorption transmission loss, nonwoven, sound absorption coefficient.*

I. INTRODUCTION

After air and water pollution, Sound pollution is the third major pollution in today's era of the continuing development of new technologies, use of more powerful machinery and increase in a number of vehicles leads to increase the noise pollution. Its impact on the environment and human health is a matter of concern. Looking at the importance of this, so many students, researcher, and academician of textile had shown their interest in this field. Measurement of an acoustic coefficient is important to determine the acoustic properties of textile materials. Sound coefficient indicates the amount of incident sound absorbed by a material. To measure the sound absorption coefficient first sound waves are generated using sound source and transmitted it through medium towards the samples. There are two methods generally used for measuring the normal incident sound absorption coefficient for small sample using the sound absorption coefficient. One is the standing wave ratio standardized in ISO 10534-1, and the other is the transfer-function method standardized in ISO 10534-2 [1][2]. In standing wave ratio methods pressure at two microphones and standing wave pattern are used to measure the sound absorption coefficient and in case of transfer function method, the reflection coefficient is used. A. Farina and P. Fausti [3] gave other methods of calculating the sound absorption coefficient. Impedance tube testing available at few in India and the cost of the commercially available instrument is not affordable. The present study gives an idea about the custom-building of impedance tube testing facility.

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* Correspondence Author
Prof. (Dr.) S. S. Bhattacharya*, Textile Engineering Department, The M. S. University, Baroda, India.
D.V. Bihola, PhD Student of Textile Engineering,, The M. S. University, Baroda, India., presently working as Assistant Prof. Textile Technology, L.D. College of engineering, Ahmedabad, India.

II. LITERATURE REVIEW

Gibiat and Laloe [4] proposed a two microphone three calibration method. In this method, the impedance of unknown device calculated using impedance of three known devices and the transfer function measured to find out the sound absorption coefficient.

Jeong and Chang [5] presented an optimization method to improve reproducibility using flow resistivity methods. Garai and Pompoli [6] gave echo impulse technique to measure the sound absorption coefficient, which requires further processing of results to get accurate results. The sound absorption coefficient measured using a wide range of frequencies and these methods introduce some error in the measurement setup. They suggested various procedures to minimize these errors. In transfer function methods bias and a random error occur between two microphone positions. Air gap behind the sample also alter the results. Pilon et al [7] investigated the effect of an air gap and found that the air gap behind the sample affects the results.

Abom [8] investigated that space between two microphone should be minimized to reduce errors due to pressure at the microphone. They also stated the errors were minimized by decreasing the tube length, having a non-reflective source end and keeping the microphone as close as possible. The frequency also depends on complex reflection and normalized acoustic impedance were investigated in a verified systematic work [9].

Cho and Nelson [10], proposed improved multiple methods to measure transfer function value. They also calculated acoustic impedance from transfer function with a different combination of the microphone using least square curve fitting and optimizing the response of microphone position. This paper gives an idea about the development of customized impedance tube to measure the sound absorption coefficient as per ISO 10534-2 [2].

2.1 Transfer-function method.

The test sample is mounted at one end of the impedance tube. Plane waves are generated in the tube by sound source emitting random or pseudo-random sequence, and pressure is measured at two locations close to the sample. The sound absorption coefficient is determined using a complex acoustic transfer function of the two microphones. The frequency range depends on the diameter of the tube and the distance between the two microphone.

The normal incidence reflection factor can be calculated using the formula[2].

$$r = |r|\, e^{j\phi_r} = \frac{H_{12} - H_I}{H_R - H_{12}}\, e^{2jk_0 x_1} \qquad (1)$$

Where:

r is a reflection factor of normal incidence;

x_1 is the distance between the sample and the further microphone location;

j is square root of minus one

k is $2\pi f/c$ (m^{-1})

ϕ_r is the phase angle of the normal incidence reflection factor;

H_{12} is the transfer function from microphone one to two, defined by the complex ratio $p_2/p_1 = S_{12} / S_{21}$;

H_R and H_I are the real and imaginary part of H_{12};

α is Sound absorption coefficient;

The sound absorption coefficient can be calculated as [2]:

$$\alpha = 1 - |r|^2 = 1 - r_r^2 - r_i^2 \qquad (2)$$

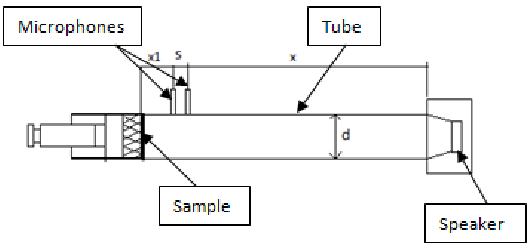

Figure 1 Impedance tube

Where,

X1 is distance between sample and furthest microphone;

S is distance between two microphones;

X is distance between sound source and first microphone;

d is diameter of impedance tube.

III. DEVELOPMENT OF IMPEDANCE TUBE

The impedance tube was designed and constructed as part research work. The aim was to develop an impedance tube using less expensive materials and still obtain accurate and reliable testing results. Two tube having diameter 100mm and 30mm were developed to measure the sound abruption coefficient with different frequency. 100 mm tube was made of mild steel whereas a 30mm tube was made using stainless steel. The holes for the microphone were drilled with ±0.2 millimeters. Figure 1 shows a schematic diagram of the impedance tube. The hard reflective piston was sealed and it acts as a backing to the sample fabric. It slides in the inner wall of the tube, which is mounted in continuation of the transfer-function tube. To generated sound inside the impedance tube on other ends of the tube, the speaker was fitted. Open-source software Visual Analyser was used to generate the impedance sound with different frequency and to measure pressure at two microphone position. sound absorption coefficient was measured using Transfer-function method with the help of equation no. 1 and 2.

3.1 Tube Diameter And Microphone Spacing

The tube is a most important functional as well as a structural part of the apparatus. The tube has a test sample holder at one end and a sound source at the other. The impedance tube shall be straight with a uniform cross-section and smooth, nonporous wall without holes except for the microphone in the tube. The tube wall thickness was selected in such a way that the tube is not excited to vibration by the sound and shows no vibration resonances in the working frequency range of the tube. For both tube 5mm wall thickness was selected. It also governs the operating frequency range of the apparatus. For a wider range of frequencies to be included in the measurement, tubes with different diameter and length are required. Therefore tube with 100mm and 30mm was developed to study the sound absorption coefficient at a wide range of frequencies. The frequency range is defined as $f_l < f < f_u$, where f_l is lower working frequency limit, f_u is upper working frequency limit and f is the operating frequency. The lower frequency limit is dependent on the spacing between the microphone and the accuracy of the measurement. The rule of thumb suggests microphone spacing should be more than one percent of the wavelength of the lowest frequency of interest, provided a condition of equation (5) are satisfied.

The conditions for upper and lower limits of frequencies are defined as below for circular tube with "d" diameter [2].

$$f_u < \frac{0.58C_0}{d} \quad \text{or} \quad d < \frac{0.58C_0}{f_u} \qquad (3)$$

$$f_l < \frac{0.01C_0}{s} \quad \text{or} \quad s < \frac{0.01C_0}{f_l} \qquad (4)$$

$$S < \frac{0.45C_0}{f_u} \qquad (5)$$

Where,

C_0 is the speed of sound (m/s) in the air;

d is the inside diameter of the tube in meters;

S is the distance between pair of microphones in meters.

Generally, frequency range from 100 Hz to 6300 Hz is considered for any textile material to be assessed as per acoustical performance [2]. Space between two microphone plays a critical role in determining the lower cut off frequency of the tube. The spacing between the microphone is fixed by the lower usable frequency of an incident sound wave. Generally, 50mm of microphone spacing is generally used in 100 mm diameter tube and 20 mm spacing is used in a tube having a 30mm diameter.

In this case, mild steel pipes with 100 mm diameter, 5mm wall thickness and having 1000 mm length was selected to produce a useful frequency range of 34 -1543Hz (100 mm Spacing between two microphones). Stainless steel pipes were used to construct 30 mm diameter impedance tube having 5 mm wall thickness and 955 mm length. This tube supports the frequency range of 171 – 6631Hz (20 mm spacing between two microphones).

3.2 Sound Source and Microphone

A speaker was used to produce an incidence wave in the interested frequency range. The backside of the speaker was seal with sound absorption material to avoid any reflected wave to interfere with the forward progressing plane wave. A microphone was positioned in such a way that it does not disturb the plane wave and be able to measure the pressure level inside the impedance tube. Each microphone mounted with diaphragm flush with an interior surface of the tube. Microphone grid sealed tight to the microphone housing and sealed between a microphone and mounting hole. A microphone is removable and holder sealed in such way that sound wave will not leak into the surrounding atmosphere. Lapel microphone with 360^{O} omnidirectional configuration and which is capable to capture each and every sound wave perfectly was used. Microphone diameter is 2.7mm and working frequency range is 20-20kHz. An amplifier having 4Ω – 8 Ω output impedance was used. Multichannel sound card with 7.1 channel of dynamic sound was sued. To generate different frequency sound open-source Visual Analyzer software was used.

IV. ASSEMBLY OF IMPEDANCE TUBE

Various sections of tubes cut to the desired length and fixed with flanges and organ welding were used to make it airtight. Schematics as shown as figure1 and actual photographs of the complete apparatus and various section shown in figure 2.

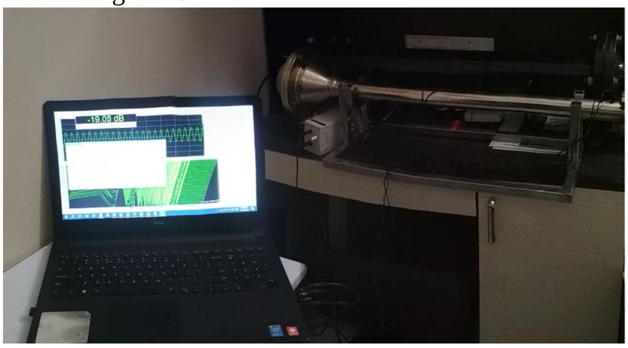

Figure 2 Assemble tubes for the sound absorption coefficient

In case of, 100 diameter tube sample was mounted at distance 800 mm from the sound source. The position of nearest microphone kept in such a way that distance between sample and microphone was 100 mm. Distance between two microphones was 100mm and the length of the sliding plunger was kept 200 mm. For 30mm tube sample was mounted at 755mm from sound source, the distance between a sample and closed microphone was 25mm and the distance between to microphone was 20mm. Plunger with 200mm length also attached to create an air gap between sample and back plate.

V. VALIDATION STUDY

The custom-built impedance tube and measuring system are validated by comparing results obtained with those measured from a commercial impedance tube available at PSG College, Coimbatore using the same sample. The commercial reference tube used is industry-standard Josts Engineering Company Limited, Bengaluru, Model No - 3160 - A – 042. The diameter of the tube used for measurement is 99.90 mm and 29.90 mm with a distance of the sample from the sound source 635 mm and 755 mm respectively. Microphone space between two microphones is 50 mm and 25 mm for 100 mm diameter tube and 30 mm diameter tube respectively. Distance between a sample and its nearest microphone for 100 mm diameter is 90mm and for 30 mm diameter tube, it is 25mm. the measurement is carried out using Bruel & Kjaer – Pulse lab shop version 21.0.0.567 software. Two different types of non woven fabric as shown in Figure 3, made of using kapok and milkweed fiber were used to validate the results.

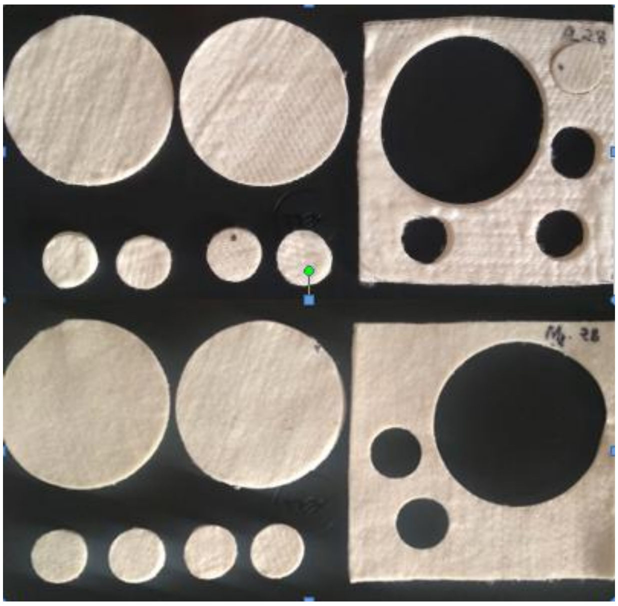

Figure 3 Samples used during validation (A28-Kapok fiber nonwoven fabric, M28-Milkweed fiber nonwoven fabric)

Samples made of kapok and milkweed fiber were selected for validation. Kapok and milkweed both are naturally hollow fiber, due to hollow structure of the fiber both fibers have a potential to be used as natural acoustic material for an acoustic application. Sample were tested to measure sound absorption coefficient using the developed tube and after that tested at NBA Accredited laboratory, PSGTECHS COE INDUTECH LABORATORY, Coimbatore to validate the performance and accuracy of developed tube.

It was observed that test results obtain from commercial impedance tube shown the similar trends as obtained using customized impedance tube. The test results are given in table 1 and table 2.

Table 1Comparison of Sound absorption Coefficient for kapok fiber nonwoven fabric

Sound Absorption Coefficient (α)-Kapok Fibre (A28)			
Frequency (Hz)	PSG College, Impedance tube results	Frequency (Hz)	Custom-build, Impedance tube results
250	0.04	250	0.07
500	0.06	500	0.1
1000	0.18	1000	0.21
2000	0.41	2000	0.44
2500	0.54	2500	0.52
3150	0.63	3150	0.67
4000	0.72	4000	0.75
5000	0.77	5000	0.76
6300	0.81	6300	0.83

Table 2 Comparison of Sound absorption Coefficient for Milkweed fiber nonwoven fabric

Sound Absorption Coefficient (α)-Milkweed Fibre (M28)			
Frequency (Hz)	PSG College, Impedance tube results	Frequency (Hz)	Custom-build, Impedance tube results
250	0.03	250	0.07
500	0.05	500	0.1
1000	0.11	1000	0.17
2000	0.23	2000	0.25
2500	0.36	2500	0.4
3150	0.48	3150	0.51
4000	0.61	4000	0.61
5000	0.74	5000	0.73
6300	0.81	6300	0.81

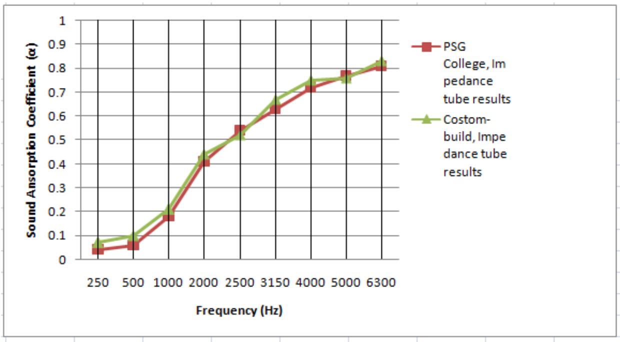

Figure 4 Comparison of Commercial Vs Developed Tube - Kapok fiber nonwoven fabric

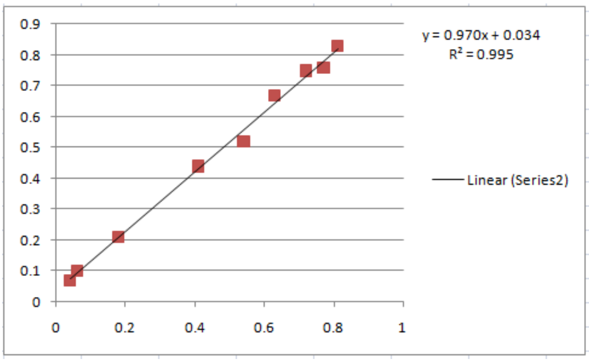

Figure 5 Correlation of Commercial Vs Developed Tube – Kapok fiber nonwoven fabric

Figure 4 shows kapok fiber non woven fabric results of sound absorption testing, while figure 5 shows the correlation between results obtained for kapok fiber sample using commercially available impedance tube and developed impedance tube. From figures, it is clear that both the impedance tube gives similar results and the correlation value of r is 0.99 indicate there is a high degree of a positive linear relation between results for both the tube.

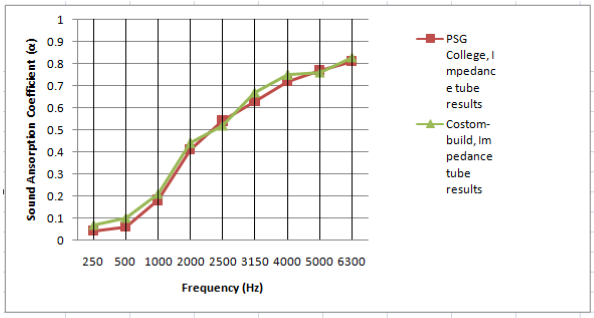

Figure 6 Comparison of Commercial Vs Developed Tube - Milkweed fiber nonwoven fabric

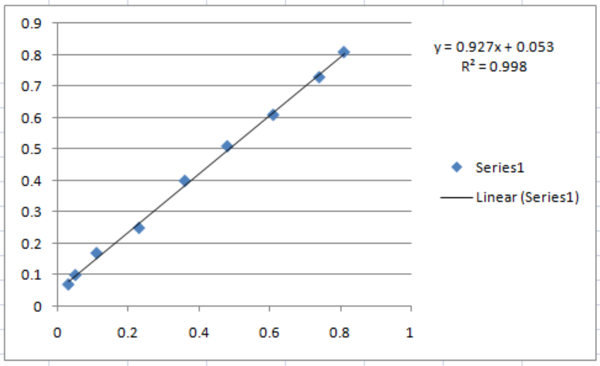

Figure 7 Correlation of Commercial Vs Developed Tube – Milkweed fiber nonwoven fabric

Figure 6 shows milkweed fiber nonwoven fabric test results in comparison with commercial and developed impedance tube. From the figure, it can be said that similar results were obtained from both tube. Figure 7 indicates the correlation between the sound absorption coefficient between the commercially available tube and developed tube for milkweed fiber nonwoven fabric results. observing correlation value of r is 0.99 and the scatter diagram it can be said that there is a high degree of linear correlation between results obtain form commercial available tube and developed impedance tube.

VI. CONCLUSION

An impedance tube for measurement of the sound absorption coefficient according to ISO 10534-2 was designed and produced with 100 mm and 30 mm diameters. Nonwoven fabric sample specially designed for the acoustic purpose was tested using developed impedance tube and the same samples were tested at PSG college, Coimbatore to validate developed impedance.

From obtaining results and correlation coefficient value for commercially available and developed impedance tube it can be said that developed impedance gives similar results to the commercial tube with high degree positive linear correlation.

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