International Journal of Advance Research in Science and Engineering
Volume No.08, Issue No.09, September 2019
www.ijarse.com
IJARSE
ISSN: 2319-8354

Design and Construction of Impedance Tube for Sound Absorption Coefficients Measurements

Prof. (Dr.) S. S. Bhattacharya[1], Asst. Prof. D. V. Bihola[2]

1. *Textile Engineering Department, The M. S. University, Baroda, India*
2. *Textile Technology Department, L.D. College of Engineering, Ahmedabad-380015, India.*

ABSTRACT

To assess the acoustic performance of textile material a sound absorption coefficient needs to be measured using an impedance tube. There are different techniques available to measure the sound absorption coefficient. The impedance tube is the most popular technique to measure normal sound absorption and transmission loss, due to its added advantages like ease of construction, low cost, its portability, fast results providing and a very small sample is required to measure the acoustic properties of the textile materials. Unfortunately, the cost of commercially available impedance tube and software used for measurement of sound absorption coefficient is very high. This paper provides information about the design and construction of a customised impedance tube suitable for researchers. First the theoretical background of the transfer function methods is discussed according to ISO 10534-2. The analytical formulation needs to be considered while designing the impedance tube for different working frequency also presented. The construction details of impedance tube like 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 performance of impedance tube, same samples were tested using 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 the obtained results.

.

Keywords*: *Sound absorption, sound absorption coefficient, Acoustic, Impedance tube, Transfer function methods.

1. INTRODUCTION

Sound pollution is the third major pollution in today's era of the continuing development of new technologies, the use of more powerful machinery and an 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].

The methods using standing wave ratio is well established, but slow, so it is substituted with transfer-function methods because of its quickness and accuracy. There are also other methods for calculating the absorption coefficient using a tube [3]. Jeong and Chang [4] presented an optimization method to improve reproducibility using flow resistivity methods. Gibiat and Laloe [5] 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.

Cho and Nelson [6], 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. Garai and Pompoli [7] 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. 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. Impedance tube testing available at few places in India and the cost of the commercially available instrument is not affordable. The present study gives an idea about the design and construction of the impedance tube to measure the sound absorption coefficient as per ISO 10534-2 [2].

2. THEORY AND MEASUREMENT OF SOUND ABSORPTION

There are two standard methods used to measure the sound absorption coefficient for small samples: one using a standing wave ratio [1], and other is transfer function method [2].

2.1 METHOD USING STANDING WAVE RATIO

This method is considered that there is only a plane incident and reflected waves propagating along the tube axis in the testing tube. The incident plane sinusoidal standing wave is generated by a loudspeaker placed at one end of the tube, at the other end of the tube sample mounted and it is backed with a hard reflective end. Following equation used for the measurement in 1/3 octave frequency band. The standing wave ratio is defined by using the equation (1):

$$S = \frac{|P_{MAX}|}{|P_{MIN}|} \tag{1}$$

The reflection factor can be easily defined as given in equation (2):

$$|r| = \frac{S-1}{S+1} \tag{2}$$

Yielding the sound absorption coefficient α for plane waves using equation (3):

$$\alpha = 1 - |r|^2 \tag{3}$$

Where,

S standard wave ratio

P_{MAX} maximum values of sound wave pressure

P_{MIN} minimum values of sound wave pressure

r reflection factor

α is the sound absorption coefficient

2.2 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 working frequency range depends on the diameter of the tube and the space between the two microphones.

The normal incidence reflection factor can be calculated using the equation (4),

$$r = |r|\, e^{j\phi_r} = \frac{H_{12} - H_I}{H_R - H_{12}}\, e^{2jk_0x_1} \tag{4}$$

Where:

r is a reflection factor of normal incidence;

x_1 is the distance between the sample and to its nearest microphone;

j is square root of minus one

k_0 is wave number $=2\pi f/c$ (m^{-1}) = ω/c; where c is speed of sound

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 using equation (5),

$$\alpha = 1 - |r|^2 = 1 - r_r^2 - r_i^2 \tag{5}$$

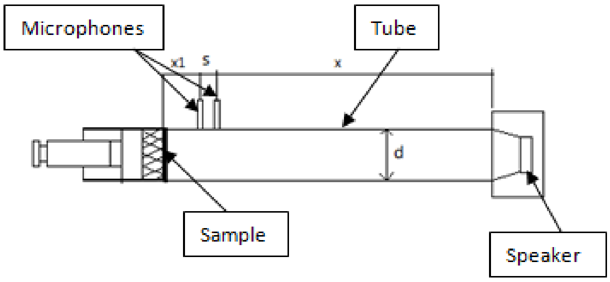

Figure 1 Impedance tube

Where,

x_1 is a distance between a sample and to its nearest microphone;

S is a distance between two microphones;

x is a distance between a sound source and first microphone;

d is the diameter of the impedance tube.

3. DESIGN AND CONSTRUCTION OF IMPEDANCE TUBE

The impedance tube was designed and constructed as part of the research work. The aim was to develop an impedance tube using low cost materials without compromising in the accuracy and reliability of 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 accuracy. Figure 1 shows a schematic diagram of the impedance tube. On one side of the impedance tube speaker is mounted to generate the sound and on other side of the impedance tube test sample mounted with hard reflective piston. It 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. A laptop was used to generate sound, data acquisition system, and display. Amplifier and signal analyzer were connected with laptop. Amplifier connected between laptop and sound source or speaker. Signal analyzer used to connect laptop and two microphones. Figure 2 shows the schematic diagram of experimental setup of impedance.

International Journal of Advance Research in Science and Engineering
Volume No.08, Issue No.09, September 2019
www.ijarse.com
IJARSE
ISSN: 2319-8354

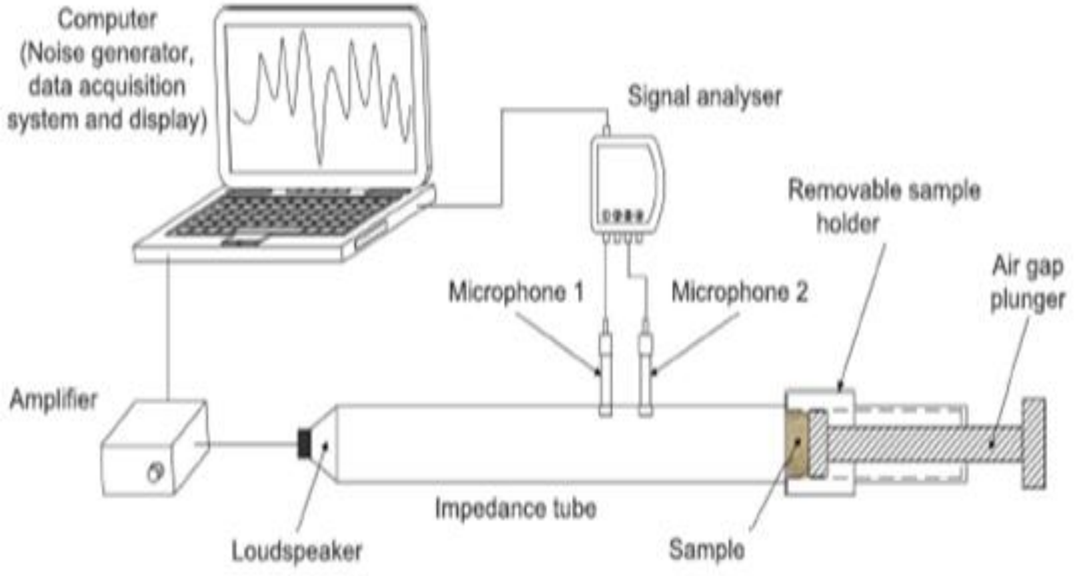

Figure 2 Experimental setup of impedance tube

Open-source software Visual Analyser was used to generate the sound of different frequency and to measure pressure at two microphone position. The sound absorption coefficient was measured using the Transfer function method with the help of equation no. 4 and 5. Table 1 indicates the various components used to develop impedance tube.

Table 2 Impedance tube component list

Sr. no.	Impedance tube component	Quantity
1.	Sound Source (Speaker)	1
2.	Microphone	2
3.	Stainless steel tube	1
4.	Stainless steel end caps	1
5.	Sample holder	1
6.	Amplifier	1
7.	Laptop with a sound card	1

Various sections of tubes cut to the desired length and fixed with flanges and organ welding were used to make it airtight. Figure 1 shows the schematics diagram and figure 3 shows the actual photographs of the complete apparatus and various sections.

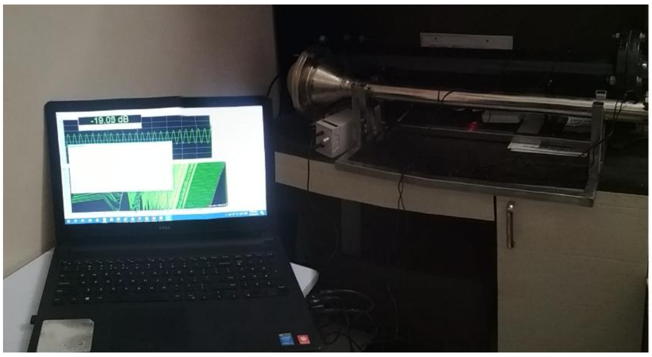

Figure 3 Assemble tubes for the sound absorption coefficient

In case of, 100 diameter tube samples were 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 a 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 backplate.

3.1 DESIGN CONSIDERATION FOR MICROPHONE SPACING AND TUBE DIAMETER

The tube is the 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. For a wider range of frequencies to be included in the measurement, Impedance tubes with different diameter and length are required for a wider range of frequency to be included in the measurement. Therefore, the tube with 100mm and 30mm were developed to study the sound absorption coefficient at a wide range of frequencies. The frequency range is defined as $f_l < f < fu$, where f_l is lower working frequency limit, fu is upper working frequency limit and f is the working 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 wavelengths of the lowest frequency of interest, provided a condition of equation (8) satisfy. The conditions for upper and lower limits of frequencies are defined as below for circular tube with “d” diameter [2].

$$f_u < \frac{0.58C_0}{d} \quad \text{or} \quad d < \frac{0.58C_0}{f_u} \tag{6}$$

$$f_l < \frac{0.01C_0}{s} \quad \text{or} \quad s < \frac{0.01C_0}{f_l} \tag{7}$$

$$S < \frac{0.45C_0}{f_u} \tag{8}$$

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 microphones plays a critical role in determining the lower cut off frequency of the tube. The spacing between the microphones 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.

4. 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 4, made of using kapok and milkweed fibre were used to validate the results.

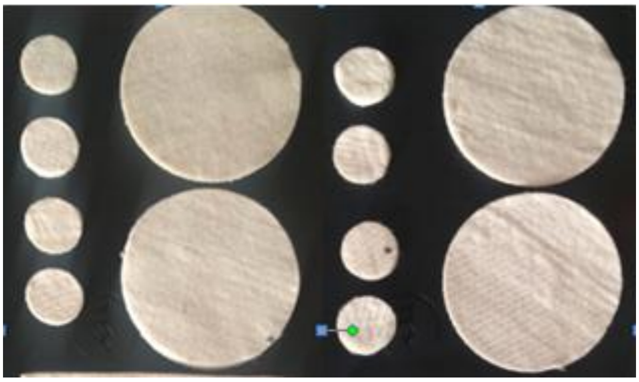

Figure 4 Test Samples

Samples made of kapok and milkweed fibre were selected for validation. Kapok and milkweed both are naturally hollow fibre, due to hollow structure of the fibre both fibres have a potential to be used as natural acoustic material for an acoustic application. Samples 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 a 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 2.

International Journal of Advance Research in Science and Engineering
Volume No.08, Issue No.09, September 2019
www.ijarse.com
IJARSE
ISSN: 2319-8354

Table 2Comparison of Sound absorption Coefficient

Sound Absorption Coefficient (α)-Kapok Fibre (A28)			Sound Absorption Coefficient (α)-Milkweed Fibre (M28)		
Frequency (Hz)	PSG College, Impedance tube results	Custom-build, Impedance tube results	Frequency (Hz)	PSG College, Impedance tube results	Custom-build, Impedance tube results
250	0.04	0.07	250	0.03	0.07
500	0.06	0.1	500	0.05	0.1
1000	0.18	0.21	1000	0.11	0.17
2000	0.41	0.44	2000	0.23	0.25
2500	0.54	0.52	2500	0.36	0.4
3150	0.63	0.67	3150	0.48	0.51
4000	0.72	0.75	4000	0.61	0.61
5000	0.77	0.76	5000	0.74	0.73
6300	0.81	0.83	6300	0.81	0.81

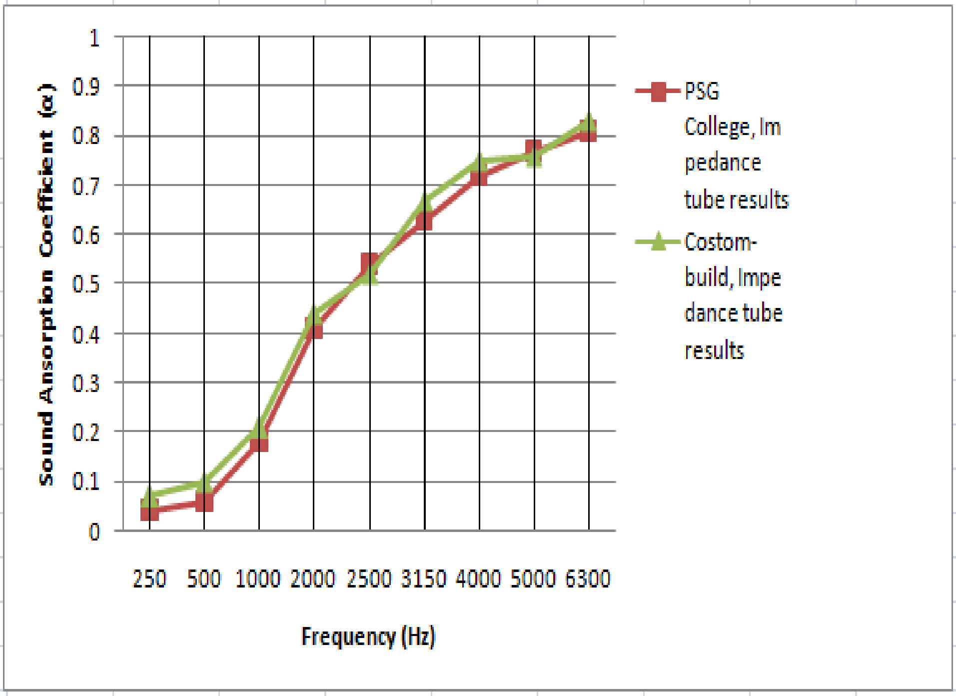

Figure 5 Kapok fibre nonwoven fabric comparison of commercial Vs developed Tube

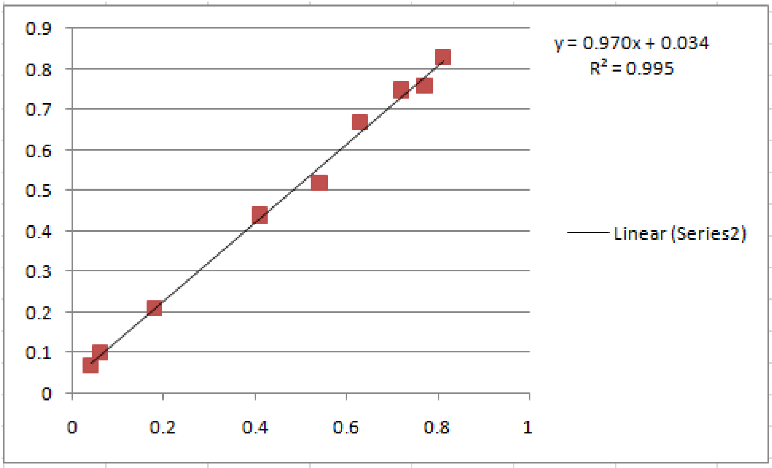

Figure6 Kapok fibre nonwoven fabric correlation of commercial Vs developed Tube

Figure 5 shows kapok fibre non woven fabric results of sound absorption testing, while figure 6 shows the correlation between results obtained for kapok fibre 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.

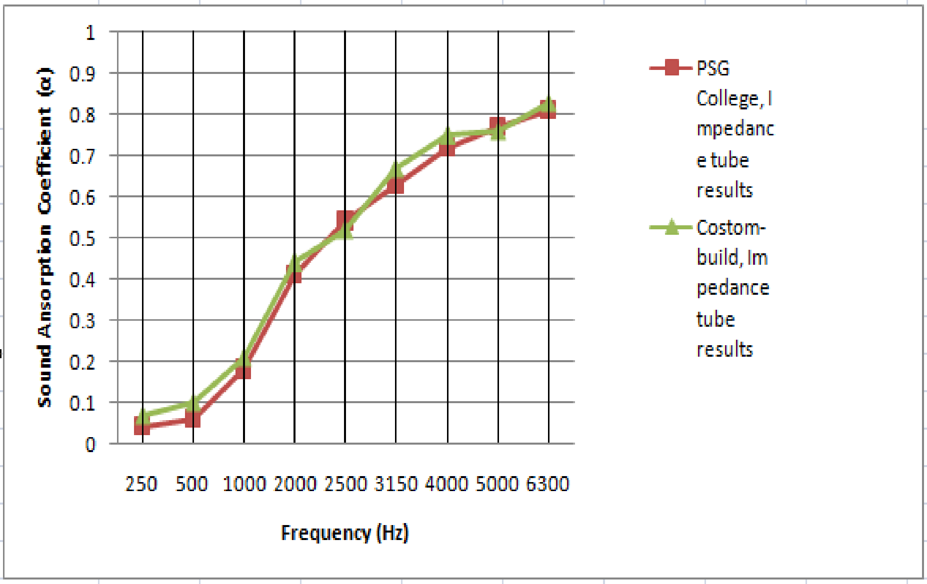

Figure7 Milkweed fibre nonwoven fabric comparison of Commercial Vs Developed Tube

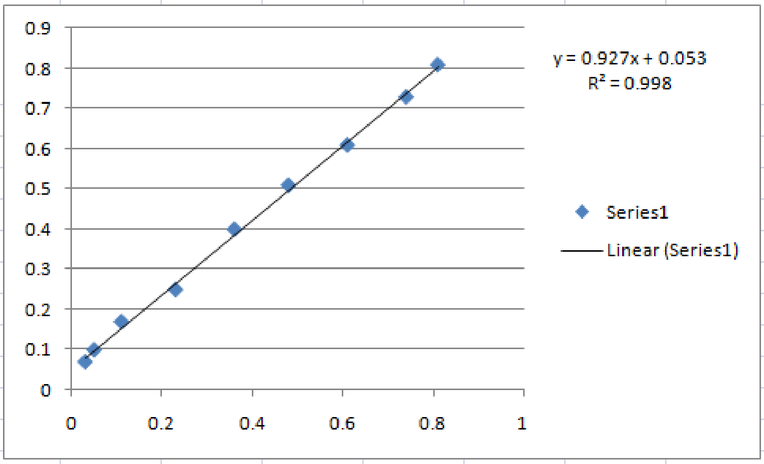

Figure 8 Correlation of Commercial Vs Developed Tube – Milkweed fibre nonwoven fabric

Figure 7 shows a milkweed fibre 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 tubes. Figure 8 indicates the correlation between the sound absorption coefficient between the commercially available tube and developed tube for milkweed fibre 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.

5. CONCLUSION

This paper describes the design and construction of the impedance tube, sine its conception to the final product. 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. Experimental results using kapok and milkweed nonwoven fabrics were presented as preliminary tests. From obtaining results and correlation coefficient value for commercially available and developed impedance tube it can be said that developed impedance gives almost similar results to the commercial impedance tube. Correlation analysis also indicates that there is a high degree positive linear correlation between results obtained from developed tube and the commercial tube.

REFERENCES

[1] Acoustics, “Determination of sound absorption coefficient in impedance tubes - Part I: Method using standing wave ratio, ISO 10534-1.”

[2] Acoustics, *Determination of sound absorption coefficient in impedance tubes - Part 2: Transfer-function Method, ISO 10534-2*. 1998.

[3] A. Farina and P. Fausti, “Standing Wave Tube Techniques for Measuring the Normal Incidence Absorption Coefficient: Comparison of Different Experimental Setups.,” *Proc. 11th. Int. FASE Symp.*, pp. 1–5, 1994.

[4] C. H. Jeong and J. H. Chang, “Reproducibility of the random incidence absorption coefficient converted from the sabine absorption coefficient,” *Acta Acust. united with Acust.*, vol. 101, no. 1, pp. 99–112, 2015.

[5] V. Gibiat, “Acoustical impedance measurements by the two-microphone-three- calibration (TMTC) Methods,” vol. 88, no. December 1990, pp. 2533–2545, 2010.

[6] P. . Cho, Y. and Nelson, “Least squares estimation of acoustic reflection coefficient,” in *Institute of Acoustics Spring Conference 2002, Past, Present and Future Acoustics and EPSRC Theme Day in Acoustics.*, p. 8.

[7] M. Garai and F. Pompoli, “A simple empirical model of polyester fibre materials for acoustical applications,” vol. 66, pp. 1383–1398, 2005.

[8] M. Åbom and H. Bodén, “Error analysis of two‐ microphone measurements in ducts with flow,” *J. Acoust. Soc. Am.*, vol. 83, no. 6, pp. 2429–2438, 1988.