Chapter 4

Development of Impedance Tube

4.1 Construction of Impedance Tube

The impedance tube is designed and constructed as part of the present study work. The aim is to develop an impedance tube using low-cost materials without compromising the accuracy and reliability of testing results. The first impedance tube with PVC pipe having a 100 mm diameter meter is developed for initial trials, which can be used to measure sound absorption in the frequency range of 34 -1543 Hz. Generally, frequency range from 100 Hz to 6300 Hz is considered for any textile material to be assessed for its acoustical performance. To Measure the sound absorption coefficient for the frequency range from 100 Hz to 6300 Hz, which depends on the tube diameter, Another two tubes having a diameter of 100 mm and 30 mm are developed to measure the sound absorption coefficient with different frequencies. 100 mm tube is made of mild steel, whereas a 30 mm tube is made using stainless steel. The holes for the microphone are drilled with ± 0.2 millimeters accuracy. The schematic diagram of the impedance tube is shown in figure 4.1. On one side of the impedance tube, a speaker is mounted to generate the sound and on the other side of the impedance tube test sample mounted with the hard reflective piston. It is sealed, and it acts as a backing to the sample fabric. It slides in the inner wall of the tube, which is mounted in the continuation of the transfer-function tube. A laptop is used to generate sound, data acquisition systems, and display. The amplifier and signal analyzer are connected with the laptop. Amplifier connected between laptop and sound source or speaker. Signal analyzer used to connect laptop and two microphones. Figure 4.2 shows the schematic diagram of the experimental setup of impedance.

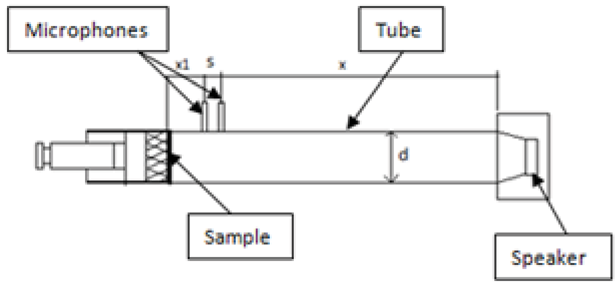

Figure 4.1: Schematic diagram of the impedance tube

Where,

x_1 = Distance between a sample and its nearest microphone;

S = Distance between two microphones;

x = Distance between a sound source and first microphone;

d = Diameter of the impedance tube.

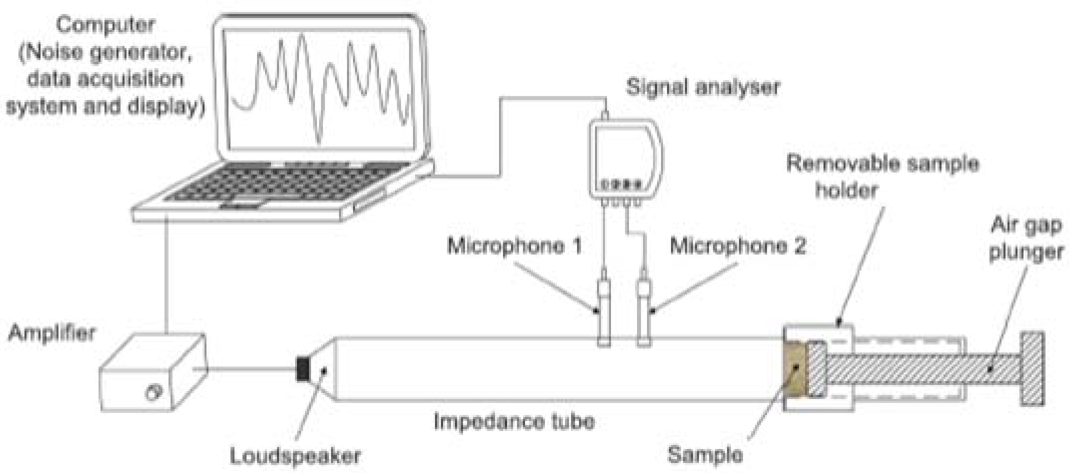

Figure 4.2: Schematic diagram of the experimental setup of impedance

Table 4.1: 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

Open-source software Visual Analyser is used to generate the sound of different frequencies and to measure pressure at two microphone positions. The sound absorption coefficient is measured using the Transfer function method with the help of equation no.2.15 and 2.16. Table 4.1 indicates the various components used to develop each impedance tube.

Various sections of tubes cut to the desired length and fixed with flanges and organ welding are used to make it airtight. Figure 4.1 shows the schematics diagram and figure 4.3 shows the actual photographs of the complete apparatus and various sections.

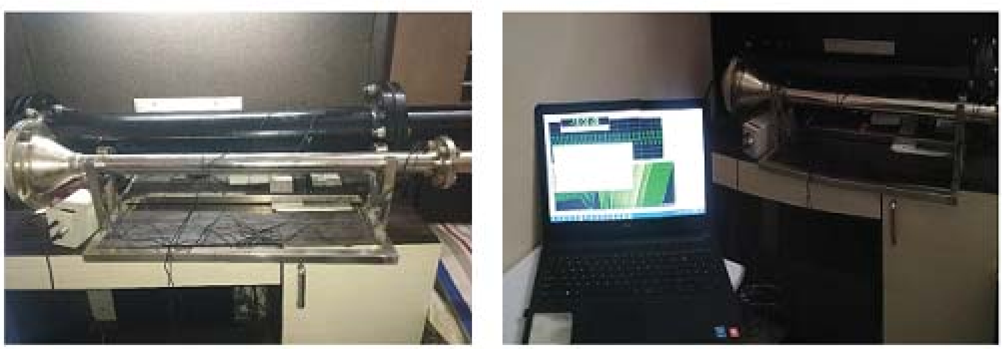

Figure 4.3: Image of experimental setup of impedance tube

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

4.1.1 Design Consideration for Microphone Spacing and Tube Diameter

The tube is the utmost important functional as well as a structural part of the apparatus [175]. 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 is 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 tubes, 5 mm wall thickness is selected. For a wider range of frequencies to be included in the measurement, Impedance tubes with different diameters and lengths are required. Therefore, the tube with 100 mm and 30 mm is developed to study the sound absorption coefficient at a wide range of frequencies. The frequency range can be defined as $f_l <$ f $<$ f_u, where f_l and f_u are lower and upper working frequency limits, respectively, and f is the working frequency [175]. The spacing between the two microphones and the accuracy of the measurement depends on the lower frequency limit. As a rule of thumb, microphone spacing should be more than one percent of the wavelengths of the lowest frequency of interest, provided a condition of equation 4.3 satisfy. The conditions for upper and lower limits of frequencies are defined as below for circular tubes with "d" diameter [117].

$$f_u < \frac{0.58C_0}{d} \quad \text{or} \quad d < \frac{0.58C_0}{f_u} \tag{4.1}$$

$$f_i < \frac{0.01C_0}{S} \quad \text{or} \quad S < \frac{0.01C_0}{f_i} \tag{4.2}$$

$$S < \frac{0.45C_0}{f_u} \tag{4.3}$$

Where,

C_0 = Speed of sound (m/s) in the air

d = Inside diameter of the tube in meters

S = 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 [117]. 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, 50 mm of microphone spacing is used in a 100 mm diameter tube and 20 mm spacing is used in a tube having a 30 mm diameter.

In this case, mild steel pipes with 100 mm diameter, 5 mm wall thickness, and having 1000 mm length is selected to produce a useful frequency range of 34 -1543 Hz (100 mm Spacing between two microphones). Stainless steel pipes are used to construct a 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).

4.1.2 Sound Source and Microphone

During an experiment, a speaker is used to produce an incidence wave in the interested frequency range. The backside of the speaker is a seal with sound absorption material to avoid any reflected wave to interfere with the forward progressing plane wave. A microphone is 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 is mounted with a diaphragm flush with an interior surface of the tube. The microphone grid sealed tight to the microphone housing and sealed between a microphone and a mounting hole. A microphone is removable and holder sealed in such a way that sound waves will not leak into the surrounding atmosphere. Lapel microphone with 360° omnidirectional configuration and which is capable of capturing every sound wave perfectly is used. The microphone diameter is 2.7 mm, and the working frequency range is 20-20kHz. An amplifier having $4\Omega - 8\Omega$ output impedance is used. A multichannel sound card with 7.1 channel of dynamic sound is used. To generate different frequency sound, open-source Visual Analyzer software is used.

4.2 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. The microphone space between the 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 90 mm, and for a 30 mm diameter tube, it is 25 mm. 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 4.4, made of using kapok and milkweed fibre are used to validate the results. Samples

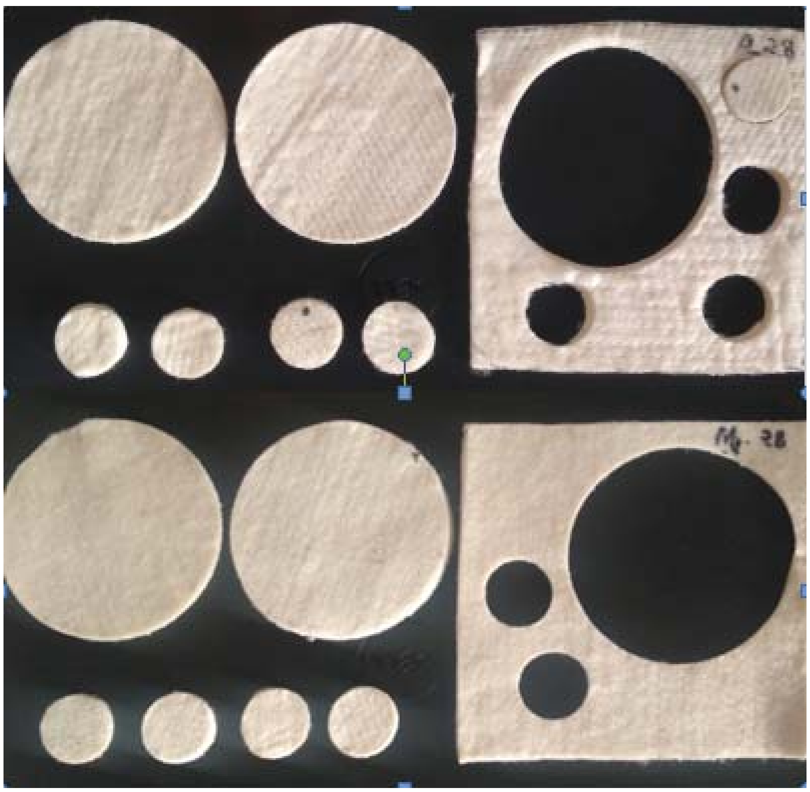

Figure 4.4: Validation Test Samples (K28-Kapok fiber nonwoven fabric, M28-Milkweed fiber nonwoven fabric)

made of kapok and milkweed fibre are selected for validation. Kapok and milkweed both are naturally hollow fibre, due to the hollow structure of the fibre both fibres have the potential to be used as natural acoustic material for an acoustic application. Samples are tested to measure the 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 is observed that test results obtain from commercial impedance tube shown the similar trends as obtained using customized impedance tube.

It is also validated by presenting the paper at the conference of Institution of Engineers (India), held on February 9-10, 2020 at Kolkata.

The following chapter deals with the analysis of the obtained results of kapok and milkweed fibre nonwoven fabric.