Analyzing the Acoustic Impedance of Natural Fiber Pads Using Impedance Tube

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Abstract- Sound absorbing materials play an important role in various fields like automobiles, conference halls, industries and many more. Synthetic fibers acoustic materials came in existence around 1970 due to public health concerns of the asbestos-based material. Now, these synthetic materials are required to be replaced by natural fiber-based materials due to their sustainability issues. In this research paper the acoustic impedance of various natural fiber pads has a been analyzed with the help of an impedance tube. It is a compact measuring apparatus to determine the acoustic impedance for a wide frequency range. The results show that the acoustic impedance of various natural fiber pads is found to be comparable with synthetic materials. Also the acoustic property of these materials is almost same in some range of frequencies with slight variations.

Keywords– Acoustic, Absorption, Frequency, Measurement, Natural Fiber, Noise, Sound, Tube, Wave.

1. INTRODUCTION

Noise pollution has become a serious problem in modern industrial and urban environments, especially in factories, buildings, and transportation systems. Excessive noise not only reduces working efficiency but also affects human health and comfort. For this reason, sound-absorbing materials are widely used to control noise and improve acoustic comfort in enclosed spaces.

Acoustic comfort in buildings, vehicles, and industrial spaces depends a lot on how effectively materials absorb unwanted sound. Particularly in the mid and high frequency range where most of the noise sources' frequencies lie. In the porous absorbers (i.e. fiber pads), moving air is forced through a network of tiny pores where energy is lost due to friction and heat exchange. The ability of absorbing incoming sound is measured through acoustic impedance at the surface which is basically the ratio between sound pressure and particle velocity at the face of the material. When the surface impedance is closer to the impedance of air, more sound enters in to the material instead of reflecting back, and more absorption happens.

Thus the acoustic impedance is not just a theoretical term, it is a function physical structure of the pad (fiber diameter, porosity, density, compression, binder use, and thickness) and measurable performance such as absorption coefficient.

Traditionally, synthetic materials such as glass wool, mineral wool, and polymer foams have been used for sound insulation and noise control. However, these materials have disadvantages such as health risks, difficult disposal, and negative environmental impact. In recent years, natural fiber–based materials have gained strong attention as eco-friendly alternatives to conventional synthetic sound absorbers. Natural fibers such as coir, kenaf, jute, hemp, sisal, banana, and agricultural wastes are biodegradable, lightweight, low-cost, and widely available. Many studies have shown that these fibers have good porous structures, which help in dissipating sound energy through friction and thermal losses inside the material pores .

Several researchers have reviewed the acoustic behavior of natural fiber composites and have reported that these materials can provide sound absorption performance comparable to synthetic materials when properly designed. Mamtaz et al. [1] explained that natural fiber composites and fibro-granular composites can be used to improve low-frequency sound absorption, and that adding granular materials and applying fiber pretreatment can significantly enhance acoustic performance. However, they also pointed out that pretreatment may reduce moisture content and affect absorption, which needs careful optimization.

The measurement and evaluation of acoustic properties of natural fibers are mainly carried out using impedance tube and reverberation room methods. Gokulkumar et al. [2] reviewed different experimental and analytical methods such as the Delany–Bazley, Biot–Allard, and Garai–Pompoli models, and reported that physical parameters like thickness, density, porosity, and airflow resistivity play a major role in controlling the sound absorption coefficient of natural fiber materials.

Experimental studies have further confirmed the importance of these parameters. Taban et al. [3] studied coir fiber panels and showed that increasing the thickness and adding an air gap behind the material significantly improves low-frequency and overall sound absorption. Their results also showed good agreement between experimental data and empirical prediction models, proving that natural fibers can effectively dissipate sound energy.

Comprehensive reviews conducted Hassan et al. [4] revealed that many natural fibers such as kapok, hemp, pineapple leaf fiber, and other agro-waste fibers can achieve sound absorption performance close to glass wool, while being safer and more sustainable. They also highlighted that fiber type, thickness, density, orientation, compression, and surface treatment strongly influence the acoustic behavior of natural fiber based acoustic materials and panels.

Although many studies have confirmed the potential of natural fibers for acoustic applications, there is still a need to develop optimized, low-cost, and sustainable sound absorbing materials with improved low frequency performance and stable properties. Therefore, the present work focuses on the development and acoustic characterization of natural fiber based sound absorbing material and aims to analyze the effect of key physical parameters on its sound absorption performance using impedance tube methods.

2. LITERATURE REVIEW

Research on porous sound absorbers has grown along two connected tracks namely empirical prediction methods and physical theories that include microstructure and frame behavior. The use of acoustic materials has become increasingly important due to the rapid growth of industrialization, urbanization, and transportation systems. Traditionally, synthetic materials such as glass wool, mineral wool, and polymer foams have been widely used for noise control. However, these materials are associated with environmental problems, disposal issues, and health risks. This has motivated researchers to explore natural fibers as sustainable alternatives for acoustic applications.

Natural fibers such as coir, kenaf, jute, sisal, hemp, banana, pineapple leaf fiber, and agricultural wastes have attracted significant attention due to their biodegradability, lightweight, low-cost, and wide availability. Many studies have shown that these fibers possess a porous structure that helps in dissipating sound energy through viscous and thermal losses inside the material. Yang et al. [5] reported that several natural fibers can achieve sound absorption performance comparable to glass fiber, especially when thickness and density are properly optimized.

One of the early experimental works on coir fiber was reported by Fouladi et al. [6], who studied the acoustic characteristics of coir fiber using impedance tube measurements. The study showed that coir fiber exhibits good sound absorption for mid and high frequencies. It was also reported that increase in pad thickness improves low frequency sound absorption. Later, Singh and Verma [7] compared acoustic properties of different natural fibers and concluded that coir and date palm fibers can replace synthetic absorbers in many engineering applications.

Berardi and Iannace [8] proposed best fit inverse models to predict the sound absorption of natural acoustic materials. The study proposed a validated method for predicted result with experimental results. Similarly, Lim et al. [9] investigated kenaf fiber and demonstrated that thickness, density, and airflow resistivity strongly influence its sound absorption ability.

Further experimental validation was provided by Taban et al. [10] investigated coir fiber composites using impedance tube method and empirical model and found that adding an air gap between the material further enhances sound absorption ability of low frequency waves.

Berardi and Iannace [11] conducted an acoustic characterization of various natural fibers and found that physical parameters such as porosity, density, and fiber diameter play an important role in sound absorption ability. Their study also highlighted that natural fiber panels, when properly designed, can match the performance of synthetic acoustic materials.

Dong et al. [12] proposed the use of additive manufacturing to fabricate lightweight microperforated acoustic panels using natural fiber reinforced composites. Their study showed that acoustic performance can be tuned by controlling perforation geometry and cavity depth. The study opened new possibilities for designing lightweight and efficient acoustic materials.

In recent years, sustainability and life cycle impact have also become important issues to be considered while developing any material. Bousshine et al. [13] compared thermal and acoustic properties of several sustainable materials and found that various agricultural and animal fibers can serve as dual thermal and acoustic insulators. Singh et al. [14] further reviewed the factors affecting acoustic performance of natural fiber-based composites and confirmed that fiber type, orientation, compression, thickness, and surface treatment have strong influence on sound absorption performance.

The broader applicability of such materials in vehicles, buildings and workplaces has been highlighted in several review studies. Although most studies report good absorption at mid and high frequencies, low frequency sound absorption remains a challenge and often requires increased thickness, air gaps, multilayer or hybrid composite design.

From the above literature, it is clear that natural fibers have strong potential to replace synthetic acoustic materials. However, there is still a need for systematic experimental studies focusing on material optimization, low-frequency performance improvement, and reliable prediction of acoustic behavior. Therefore, the present work focuses on developing and experimentally evaluating a natural fiber–based acoustic absorber and studying the effect of key physical parameters on its sound absorption performance. Mathematically, the acoustic impedance can be expressed as:

$$Z = {}^{P}\!/_{vS} \qquad \text{(i)}$$

Where p = Sound pressure
v = Particle velocity
S = Surface area of material

3. DEVELOPMENT AND WORKING OF IMPEDANCE TUBE

The impedance tube was designed and constructed using less expensive materials while obtaining accurate and reliable testing results.

Figure 1 illustrates the absorption phenomenon that occurs when a sound wave is incident on a material.

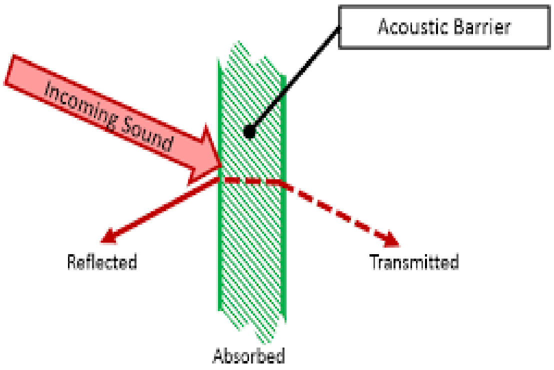

Figure 1: Sound wave absorption phenomenon

The reflection coefficient is defined as the complex ratio of sound pressure reflected at the surface of the material to the incident sound pressure. It is expressed as:

$$R = \frac{p_r}{p_i} \qquad \text{(ii)}$$

Where, p_r = Reflected sound pressure and
p_i = Incident sound pressure

Impedance tube of diameter 75 mm was developed using PVC pipe to measure the sound abruption coefficient with different frequencies. Two holes of 12 mm diameter for the microphones were drilled as shown in Figure 2. The measurement setup uses an impedance tube along with sound sensors, a speaker, an amplifier, and a test sample holder.

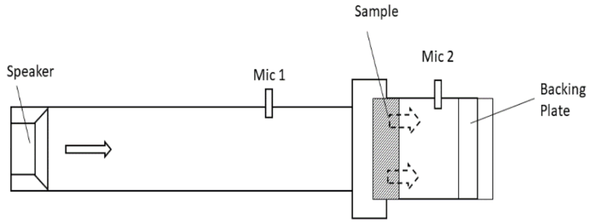

Figure 2: Schematic diagram of impedance tube

Sample holder is an important component and has a critical role in aligning test piece in required perpendicular position to the direction of traveling planer wave as shown in Figure 3.

The cross-sectional of sample holder is also kept same as the cross section of impedance tube at sound source side. The sample holder can be joined with the main impedance tube through threading or quick release coupling which requires special machining and also costly. The use of standard flanges reduces the cost of apparatus significantly; hence it is used in present work. The sample ban easily be placed between the flanges and it can be assembled and disassembled in smooth way without adding much cost of production. The designed sample holder is shown in figure 3.

Figure 3: Flanges to hold the samples

To measure the sound transmission losses, the prepared material sample is placed at the center of the same sample holder and edges are sealed with rubber sealings for avoiding flanking paths.

4. MATERIALS AND METHODS

4.1. Amplitude Absorption Method

The natural fiber test samples as shown in figure 4 are placed between holder at one end of the impedance tube. After that plane waves are generated in the tube by sound source emitting random or pseudo-random sequence. The sound pressure is measured in the form of voltage using microphones at two locations before and after sample. The sound absorption coefficient is determined using a reduction in the amplitude of the two signals obtained from microphone outputs. The frequency range depends on the diameter of the tube and the distance between the two microphones.

4.2. Circuit Diagram of the Impedance Tube

A DC 5-Volt power adapter is used to power the amplifier which is connected to the speaker and makes the complete sound generation system. The amplifier has Bluetooth connectivity which is used to connect the phone through which the sinusoidal wave is generated through an app.

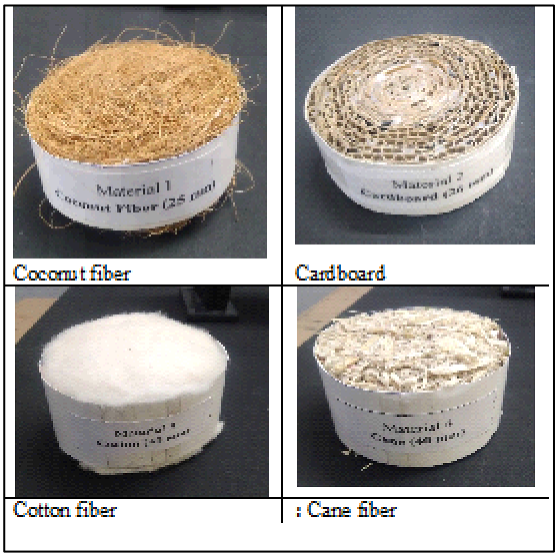

Figure 4: Natural fiber pads

The output signals generated by the microphones which are also being powered by a 5-volt adapter and are connected to the voltmeters individually to get the readings. The digital voltmeters are powered by a 9-volt battery.

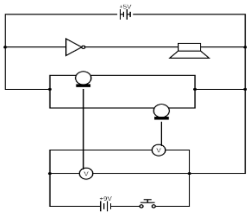

Figure 5: Circuit diagram of impedance tube setup

The figure 5 shows the schematic circuit diagram of all components. The change in the difference of the voltage for the input value will give us the absorption coefficient at a particular frequency. The data collected was used to prepare an excel sheet with an observation table and get the absorption coefficient and further analysis.

5. RESULT AND DISCUSSIONS

The working frequency for this study was taken between 400 Hz and 3000 Hz. However the range can vary from material-to-material depending on the dimensions of the tube used, the material of the tube and the working parameters and conditions of surroundings like pressure, temperature, humidity, air resistance and air absorption. The frequency as taken in sinusoidal wave form produced by function generators.

The Absorption Coefficient of different materials at given frequencies is shown in table 1.

Table 1: Absorption Coefficient of different materials

Frequency (Hz)	400	550	850	1000	1200
Coconut Fiber Pad (22 mm)	0.21	0.21	0.13	0.10	0.02
Coconut Fiber Pad (47 mm)	0.26	0.25	0.22	0.27	0.25
Cardboard Pad	0.25	0.24	0.22	0.27	0.27
Cotton Pad	0.26	0.27	0.24	0.25	0.28
Cane Pad	0.30	0.28	0.21	0.26	0.26

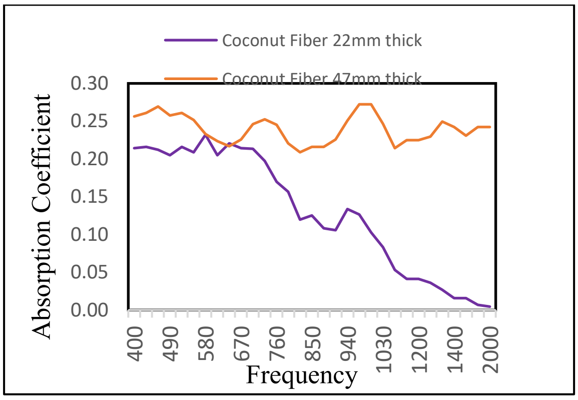

Figure 6: Sound absorption in coconut fiber pads

The curve between absorption coefficient and frequency for coconut fiber having 22 mm thickness shows that the absorption coefficients remain steady for some range of frequency and shows continuous drop after that. so, it can be concluded that cotton and cane have better acoustic absorption capacity as compared to cardboard and coconut fiber. Also, the thickness of materials directly impacts the acoustic absorption capacity of the materials. As shown in figure 7 the curve between absorption coefficient and frequency for cotton and cane is almost identical which shows that the acoustic property of both materials is almost same with slight variations and the same goes for cardboard and coconut fiber having 47 mm thickness.

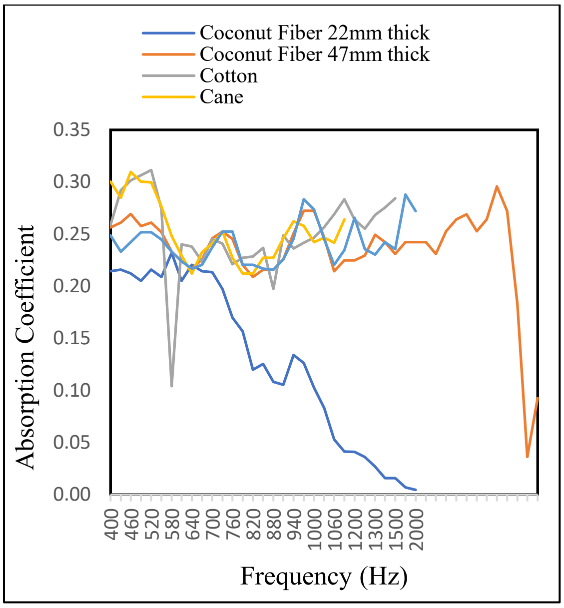

Figure 2: Comparison of absorption coefficients for various materials

6. CONCLUSION

An impedance tube was designed and fabricated to measure the sound absorption coefficient of various acoustic materials. It is suitable for measuring acoustic impedance various material samples of different thickness, with and without an air gap between the samples and the rigid surface. Also it can be used at various broadband excitation signals. It works on principle of the transfer-function method to measure normal incident sound coefficient of absorption. For small samples it is a way quicker than the tactic using standing wave ratio, and it gives a coefficient curve instead of single values obtained only for discrete sinusoidal frequencies.

However, impedance tube shows certain drops if the samples are of lower absorptance (up to 0.2) when using sine sweeps as the broadband excitation signal. A more rigid tube, smaller microphones and a second smaller tube for higher frequencies would most likely improve the measurement accuracy. The drops within the absorption coefficient curve cannot be significantly lowered whether doing a mean of a series of consequent measurements.

From the results it can be concluded that natural fibers are sustainable as acoustic materials and better replacement of synthetic materials with comparable properties.

From the results it is seen that cotton and cane have better acoustic impedance as compared to cardboard and coconut fiber pads. Also, the thickness of materials directly impacts the acoustic absorption capacity of the materials.

7. FUTURE SCOPE

In the case of acoustic tube measurement, the conventional way is limited to plane wave assumption with unidirectional theories. The failure of Ingard-Myers model due to boundary layer formation. The acoustic behavior due to variable velocity profile significantly deviates from the uniform flow assumptions. Hence, to design a better measurement technique, the linearized models to be revisited to capture the viscous effects. The study vastly relies on plane wave assumption with improvements made on computational algorithms. The impedance matching has shown a new approach specific to oblique incidence angles for 1D and 2D flow fields.

All these conventional methods have found applications in various areas ranging from acoustic imaging for medical applications to aircraft cabin noise reduction. In the recent years, external and internal noise reduction has gained attention with the increasing market focus towards comfortable urban transports.

The present work may be expanded for various other materials with wide range of frequency in future for more insights.

8. REFERENCES

[1]. H. Mamtaz, M. H. Fouladi, M. Al-Atabi, and S. N. Namasivayam, “Acoustic absorption of natural fiber composites,” Journal of Engineering, vol. 2016, Article ID 5836107, pp. 1–11, 2016, doi: 10.1155/2016/5836107.

[2]. S. Gokulkumar, P. R. Thyla, L. Prabhu, and S. Sathish, “Measuring methods of acoustic properties and influence of physical parameters on natural fibers: A review,” Journal of Natural Fibers, pp. 1–21, 2019, doi: 10.1080/15440478.2019.1598913.

[3]. E. Taban, S. Khavanin, M. H. M. Fouladi, and A. Faridan, “Study on the acoustic characteristics of natural date palm fibres: Experimental and theoretical approaches,” Building and Environment, vol. 161, Art. no. 106274, Sept. 2019.

[4]. T. Hassan, H. Jamshaid, R. Mishra, M. Q. Khan, M. Petru, M. Tichy, and M. Muller, “Factors affecting acoustic properties of natural-fiber-based materials and composites: A review,” Textiles, vol. 1, no. 1, pp. 55–85, 2021, doi: 10.3390/textiles1010005.

[5]. T. Yang, L. Hu, X. Xiong, M. Petru, M. T. Noman, R. Mishra, and J. Militký, “Sound absorption properties of natural fibers: A review,” Sustainability, vol. 12, no. 20, Art. no. 8477, 2020, doi: 10.3390/su12208477.

[6]. M. H. M. Fouladi, M. Ayub, and M. J. M. Nor, “Analysis of coir fiber acoustical characteristics,” Applied Acoustics, vol. 72, no. 1, pp. 35–42, Jan. 2011.

[7]. A. K. Singh and A. R. Verma, “Experimental study on natural fibers for green acoustic absorption materials,” American Journal of Applied Sciences, vol. 10, no. 10, pp. 1307–1314, 2013.

[8]. U. Berardi and G. Iannace, “Predicting the sound absorption of natural materials: Best-fit inverse laws for the acoustic impedance and the propagation constant,” Applied Acoustics, vol. 115, pp. 131–138, Feb. 2017.

[9]. Z. Y. Lim, M. H. M. Fouladi, and M. Ayub, “Sound absorption performance of natural kenaf fibres,” Applied Acoustics, vol. 130, pp. 107–114, Jan. 2018.

[10]. E. Taban, A. Tajpoor, M. Faridan, S. E. Samaei, and M. H. Beheshti, “Acoustic absorption characterization and prediction of natural coir fibers,” Acoustics Australia, vol. 47, no. 1, pp. 67–77, 2019, doi: 10.1007/s40857-019-00151-8.

[11]. U. Berardi and G. Iannace, “Acoustic characterization of natural fibers for sound absorption applications,” Building and Environment, vol. 94, part 2, pp. 840–852, Dec. 2015.

[12]. L. Dong, Y. Zhang, X. Li, and J. Xiong, “Fabrication of lightweight acoustic absorbers by additive manufacturing of microperforated panels with natural fiber reinforced composites,” International Journal of Lightweight Materials and Manufacture, vol. 5, no. 3, pp. 520–527, Sept. 2022.

[13]. S. Bousshine, M. Ouahmane, A. Cherif, and A. El Baroudi, “Acoustical and thermal characterization of sustainable materials derived from vegetable, agricultural, and animal fibers,” Applied Acoustics, vol. 187, Art. no. 108520, 2022.

[14]. A. K. Singh, “Dual-perspective analysis: Exploring the application of virtual reality and augmented reality in ergonomics and workspace design,” Applied Ergonomics, vol. 129, Art. no. 104612, 2025.