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Design and Construction of a Material Sound Absorption Testing Apparatus Based on a Simple Impedance Tube System

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Abstract

Noise is an undesirable sound that can negatively affect human comfort, productivity, and health, making effective noise control an important aspect of acoustic design. One practical approach to noise control is the use of sound-absorbing materials, whose performance must be evaluated using reliable testing methods. This study aims to design and construct a sound-absorption testing device based on a simple impedance tube system and to evaluate its performance in measuring and analysing sound pressure. An experimental method was employed by comparing sound pressure levels with and without test material samples at frequencies of 125 Hz, 250 Hz, 500 Hz, and 1000 Hz. The device was constructed from a 4-inch-diameter PVC tube, 100 cm long, equipped with one speaker and two microphones using the two-microphone method. Sound pressure data were recorded with Audacity and analysed for Sound Pressure Level (SPL) to determine the sound absorption coefficient using an energy comparison approach. The results indicate that the developed device effectively detects differences in sound pressure levels between conditions with and without material samples. A significant increase in sound absorption was observed at higher frequencies, particularly at 1000 Hz, where the absorption coefficient reached 0.97, indicating near-perfect absorption. In contrast, lower frequencies showed relatively small absorption values, highlighting the frequency-dependent behaviour of the tested material (rockwool). In conclusion, the simple impedance tube system can provide reliable measurements of sound absorption characteristics. The device is suitable as a preliminary testing tool and as an educational medium in acoustics, especially for evaluating the performance of sound-absorbing materials across different frequency ranges.

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	Absorption Coefficient

1. Introduction

In modern life, not all sounds are perceived as pleasant. Unwanted sound, commonly referred to as noise, can significantly disrupt human comfort in daily activities. Excessive noise levels not only degrade environmental quality but also contribute to various negative impacts, including reduced concentration, increased stress, sleep disturbances, and long-term health problems such as hearing loss (Rahmadhani et al., 2025; Halliday et al., 2014; Serway & Jewett, 2018). Therefore, effective noise control has become an essential aspect in designing acoustically comfortable environments, particularly in residential, educational, and industrial settings (Beranek & Mellow, 2012; Rossing, 2007).

One effective approach to noise control is the use of sound-absorbing materials that dissipate acoustic energy. The appropriate selection of acoustic materials can enhance room comfort while supporting its functional purpose, such as in classrooms, offices, and living spaces (Oktavia & Elvaswer, 2024; Long, 2014). As the demand for better acoustic environments increases, research in acoustic materials continues to evolve, focusing on the development of efficient, cost-effective, and environmentally friendly sound absorbers (Syahputra & Elvaswer, 2023; Everest & Pohlmann, 2015).

To evaluate a material's sound absorption performance, accurate and reliable testing methods are required. The impedance tube method is one of the most widely used techniques for measuring the sound absorption coefficient, as it requires relatively small sample sizes and does not require a large testing space (Ole & Tan, 2024; ISO 10534-2, 1998). This method is widely accepted in acoustic research for its ability to provide precise, repeatable measurements (Pierce, 1981; Kinsler et al., 2000). However, commercially available impedance tube systems are generally expensive, making them less accessible for educational institutions and small-scale laboratories (Khairunisa & Elvaswer, 2024; Firmansyah et al., 2023). This limitation has driven the development of simpler, more affordable impedance tube systems that still provide adequate measurement performance. Such developments are important to support both research activities and educational practices in acoustics, particularly in resource-limited environments (Sidiq, 2022; Widyastuti & Hidayat, 2021).

Previous studies have explored the development of impedance tube systems using simpler and more economical components. For instance, impedance tubes based on microcontroller platforms such as Arduino have been developed as portable and low-cost acoustic measurement solutions (Firmansyah et al., 2023; Sidiq, 2022). Other studies have investigated the sound-absorption characteristics of various local materials, including styrofoam, agricultural waste fibres, rice husk, and citrus peel fibre panels, demonstrating their potential as sustainable, cost-effective sound-absorbing materials (Khairunisa & Elvaswer, 2024; Andari, 2017; Kencanawati et al., 2016).

In addition to material type, several factors influence the accuracy of sound absorption measurements, including sample size, measurement methods, and frequency range. Previous research has emphasised the importance of proper calibration, the use of standard samples, and extending measurement frequency ranges to ensure reliable and comparable results (Rezita et al., 2019; Ihksan et al., 2016). Furthermore, studies by Zhang et al. and Emmerich et al. have highlighted the effectiveness of combining experimental and numerical approaches, as well as the implementation of the two-microphone transfer function method, to improve measurement stability and accuracy (Rizal et al., 2015; Relado et al., 2015).

Based on the aforementioned background, there is a need to develop a simple impedance tube-based sound absorption testing device that is easy to use, cost-effective, and reliable. Such a device is expected to serve not only as a supporting tool for acoustic learning but also as a preliminary testing instrument for characterising sound-absorbing materials in research applications.

2. Methodology

This research was conducted over approximately six months, from August 1, 2025, to January 25, 2026. During this period, the study was conducted through several systematic, well-planned stages to ensure the reliability and validity of the results. The research timeline included preparation, design, fabrication, testing, and data analysis phases.

The initial stage of the research involved preparation activities, including developing a research plan, determining appropriate experimental methods, and identifying required tools and materials. This phase was essential for establishing a clear workflow and ensuring that all components and procedures aligned with the research objectives.

The fabrication process of the testing device was carried out at the Mechanical Engineering Laboratory of Universitas Abulyatama, located in Kota Baro District, Aceh Besar Regency, Aceh Province. The laboratory facilities provided the necessary equipment and environment to properly assemble and configure the impedance tube system.

The experimental setup consisted of a simple impedance tube constructed from a 4-inch-diameter PVC pipe, 100 cm long. The system was equipped with one loudspeaker as the sound source and two condenser microphones, positioned along the tube, to measure sound pressure at two points. This configuration follows the two-microphone method, which is commonly used to analyse incident and reflected sound waves within the tube.

Data collection was conducted by measuring sound pressure under two conditions: without a material sample and with a test material sample placed inside the tube. The measurements were performed at the following frequencies: 125 Hz, 250 Hz, 500 Hz, and 1000 Hz. The sound signals were recorded using Audacity, allowing accurate capture of sound-pressure variations during testing.

The collected data were analysed for Sound Pressure Level (SPL) to evaluate the acoustic performance of the tested material. The sound absorption coefficient was calculated using an energy comparison approach based on the difference in sound pressure levels between the two testing conditions. This analysis enabled the assessment of the material’s ability to absorb sound across different frequencies.

Table 1. Equipment Specifications

No.	Component	Specification
1	Tube Material	PVC Pipe
2	Tube Diameter	4 inches
3	Tube Length	100 cm
4	Number of Speakers	1 unit
5	Number of Microphones	2 units
6	Support Stand	2 units
7	Sound Source	Speaker (4 inches)
8	Frequency Range	125 – 1000 Hz
9	Speaker Power	20 Watts
10	Microphone Type	Condenser Microphone

The equipment specifications in Table 1 indicate that the designed impedance tube system is constructed from simple, readily accessible, and cost-effective components. The use of a 4-inch PVC pipe with a length of 100 cm ensures that the system operates within an appropriate frequency range (125–1000 Hz) while maintaining one-dimensional wave propagation. The inclusion of a single speaker as a sound source and two condenser microphones enables the implementation of the two-microphone method, which is essential for accurately analysing incident and reflected sound waves. Additionally, the 20-watt speaker provides sufficient acoustic energy for testing, while the support stands ensure stability during measurements. Overall, these specifications demonstrate that the system is designed to balance performance, affordability, and practicality, making it suitable for experimental studies and educational applications in acoustics.

3. Result & Discussion

Discussion of Sound Pressure Level (SPL) Measurement

To evaluate the performance of the developed device, sound pressure level (SPL) measurements were conducted under two conditions: with and without a test material inserted into the impedance tube. The results of these measurements are presented in Table 2. The data show SPL values under both conditions, along with the SPL difference (ΔSPL) at each tested frequency. This comparison allows for the observation of how the presence of the material affects the propagation and attenuation of sound waves within the system.

Table 2. Sound Pressure Level (SPL) Measurement Results

Frequency (Hz)	SPL without Sample (dB)	SPL with Sample (dB)	ΔSPL (dB)
125	-57.39	-57.60	0.21

Frequency (Hz)	SPL without Sample (dB)	SPL with Sample (dB)	ΔSPL (dB)
250	-46.30	-46.82	0.52
500	-36.66	-36.99	0.32
1000	-54.36	-39.83	14.53

The measurements were carried out using the two-microphone method at frequencies of 125 Hz, 250 Hz, 500 Hz, and 1000 Hz. These frequencies were selected because they correspond to the standard octave-band frequencies recommended in ISO 10534-2 for impedance tube measurements. The use of these standardised frequencies ensures consistency with established acoustic testing procedures and enables reliable comparison with other studies. Additionally, employing multiple frequencies enables evaluation of material performance across a range of sound-wave characteristics.

The selected frequency range was also carefully determined to remain below the tube's cut-off frequency, based on its diameter. This condition ensures that sound propagation within the tube can be approximated as one-dimensional plane waves, a fundamental assumption in impedance tube measurements. Maintaining this condition is crucial for achieving accurate and valid results, as it minimises the effects of higher-order wave modes that could otherwise distort the measurement of sound pressure and absorption characteristics.

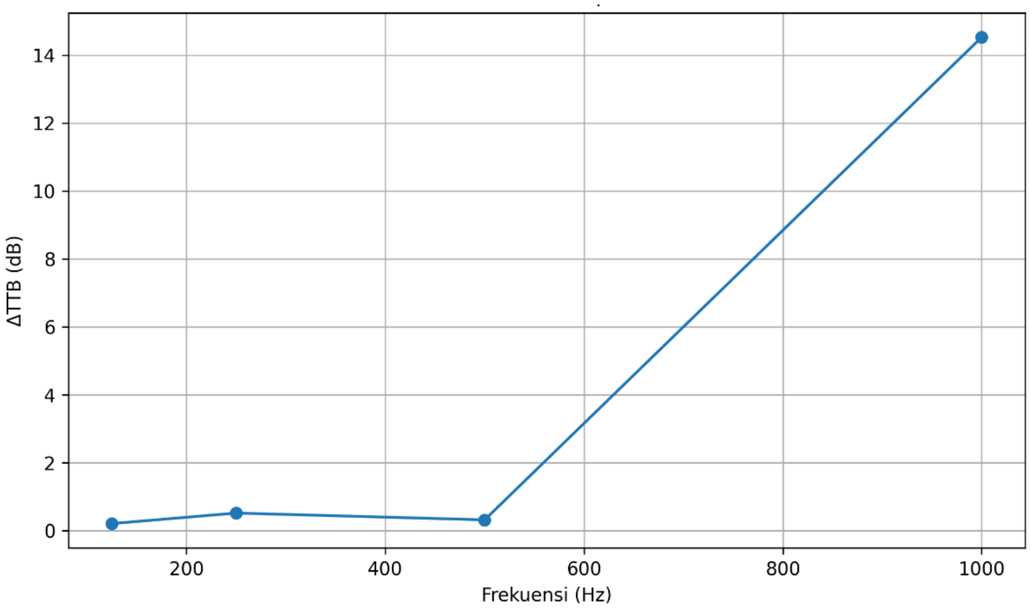

Fig. 1. Change in Sound Pressure Level (ΔSPL) with Respect to Frequency

Fig. 1 illustrates the change in Sound Pressure Level (ΔSPL) as a function of frequency due to the presence of the test material. It can be observed that the ΔSPL values remain relatively small at lower frequencies, specifically at 125 Hz, 250 Hz, and 500 Hz, indicating limited sound absorption in this range. However, a significant increase in ΔSPL is evident at 1000 Hz, where the value rises sharply. This trend clearly shows that the material exhibits much stronger sound absorption at higher frequencies. The substantial increase in ΔSPL at 1000 Hz suggests that the material is more effective in dissipating sound energy at higher frequencies. This behaviour is consistent with the characteristics of porous materials, such as rockwool, which tend to absorb high-frequency sound more efficiently due to enhanced friction and energy loss within their internal structure. In contrast, at lower frequencies, the longer wavelengths reduce the interaction between the sound waves and the material, resulting in lower absorption performance. These findings confirm that the material's acoustic performance is highly frequency dependent.

Sound Absorption Coefficient

The results presented in Table 3 show that the sound absorption coefficient (α) of the tested material varies significantly with frequency. At low frequencies (125 Hz), the absorption coefficient is very low (α = 0.05), indicating that most of the sound energy is reflected rather than absorbed. A slight improvement is observed at 250 Hz (α = 0.11), followed by a small decrease at 500 Hz (α = 0.07), suggesting that the material still has limited effectiveness in absorbing sound within the low to mid-frequency range. However, a substantial increase is observed at 1000 Hz, where the absorption coefficient reaches α = 0.97, indicating near-perfect sound absorption. This trend confirms that the material, likely due to its porous structure, performs much more effectively at higher frequencies, where sound waves are more easily dissipated through internal friction and energy conversion within the material.

Table 3. Calculation of Sound Absorption Coefficient

Frequency (Hz)	Sound Absorption Coefficient (α)
125	0,05
250	0,11
500	0,07
1000	0,97

Fig. 3 presents the relationship between the sound absorption coefficient (α) and frequency for the tested material. The graph shows that at lower frequencies, specifically 125 Hz, the absorption coefficient is very low (α ≈ = 0.05), indicating minimal sound absorption. A slight increase is observed at 250 Hz (α ≈ 0.11), followed by a decrease at 500 Hz (α ≈ 0.07), suggesting that the material exhibits inconsistent, generally weak absorption in the low-to-mid frequency range. These fluctuations imply that the material's structure is not sufficiently effective at interacting with longer-wavelength sound waves, resulting in most of the acoustic energy being reflected rather than absorbed.

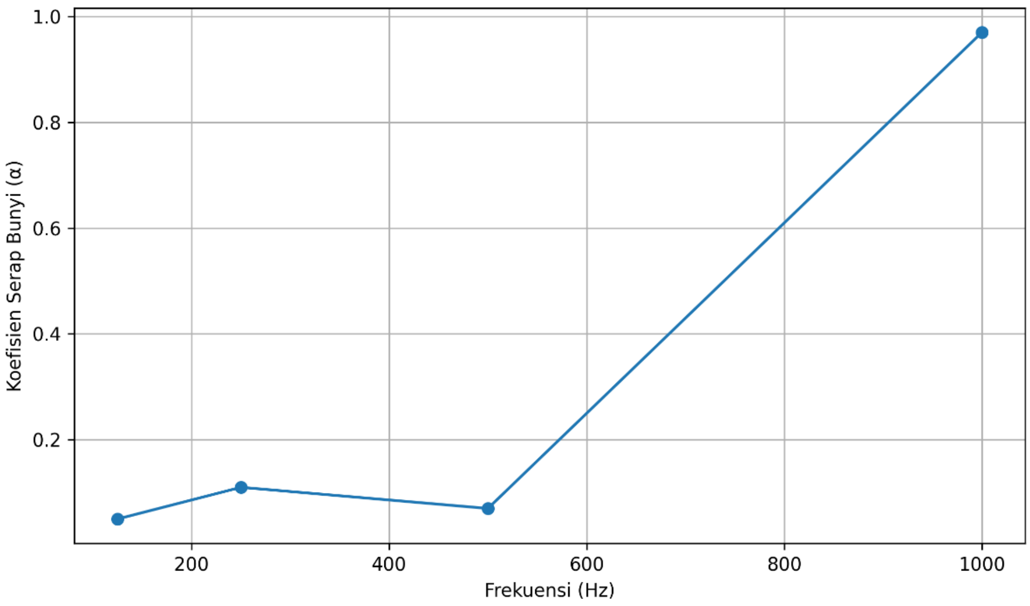

Fig. 3. Sound Absorption Coefficient (α) vs Frequency

In contrast, a significant increase in the absorption coefficient is observed at 1000 Hz, where α reaches approximately 0.97, indicating near-total sound absorption. This sharp rise demonstrates that the material performs very effectively at higher frequencies, consistent with the behaviour of porous materials such as rockwool. At higher frequencies, sound waves have shorter wavelengths, allowing them to penetrate the material more easily and undergo energy dissipation through friction and viscous losses within the pores. This result highlights the material's strong frequency-dependent acoustic performance and confirms its suitability for applications targeting high-frequency noise control, while additional modifications may be required to improve its effectiveness at lower frequencies.

This study offers novelty by developing a simple, low-cost impedance tube system that uses readily available components while still providing reliable measurements of sound absorption characteristics. Unlike conventional commercial systems, which are often expensive and less accessible, the proposed design demonstrates that accurate acoustic testing can be achieved with a simplified configuration, making it suitable for educational and preliminary research. However, several limitations should be noted. The frequency range is limited to 125–1000 Hz, which restricts the evaluation of material performance outside this range, particularly at very low or high frequencies. Additionally, the testing was conducted under controlled laboratory conditions without extensive calibration against standard reference instruments, which may affect measurement accuracy. The study also focuses on a single material (rockwool) and does not explore variations in thickness, density, or alternative materials. Therefore, future research should aim to expand the frequency range, improve calibration procedures, and investigate a broader range of materials and configurations to enhance the system's robustness and applicability.

4. Discussion

Based on the measurement results, a clear difference in Sound Pressure Level (SPL) can be observed between the condition without a sample and the condition with the rockwool sample at each tested frequency. This difference indicates that part of the incident sound wave energy is absorbed by the material, as reflected by the decrease in ΔSPL and the increase in the sound absorption coefficient (α). In general, the magnitude of ΔSPL increases with increasing frequency, suggesting that the absorption performance of rockwool is strongly dependent on sound frequency.

At 125 Hz, the measured ΔSPL is 0.21 dB, with an absorption coefficient $\alpha = 0.05$. These values indicate that most of the sound energy is reflected rather than absorbed. This behaviour is consistent with acoustic theory, which predicts that thin or low-density materials are generally ineffective at absorbing low-frequency sound because the wavelength is relatively long compared to the material thickness.

In the mid-frequency range of 250–500 Hz, the ΔSPL values range from 0.52 dB to 0.32 dB, with absorption coefficients between $\alpha = 0.11$ and $\alpha = 0.07$. At these frequencies, there is a noticeable increase in sound absorption compared to the low-frequency range. However, a significant portion of the sound energy is still reflected, indicating that the thickness and density of the rockwool are not yet sufficient to provide substantial attenuation.

At 1000 Hz, a significant increase in ΔSPL is observed, reaching 14.53 dB, with an absorption coefficient of $\alpha = 0.97$. This result indicates that nearly all incident sound energy is absorbed by the material. The high absorption performance at this frequency is attributed to the porous structure and optimal density of rockwool, which facilitates the conversion of sound energy into heat through friction within the material's pores.

These findings demonstrate that the designed impedance tube system can effectively detect variations in sound energy and accurately measure acoustic properties. The testing method used in this study is therefore considered reliable for evaluating the sound absorption characteristics of materials. From a practical perspective, rockwool is highly effective as a sound absorber at high frequencies, making it suitable for applications such as acoustic panels, echo reduction, and indoor noise control.

Overall, the results indicate that several factors, including frequency, thickness, density, and porosity, influence a material's sound absorption performance. This is consistent with fundamental acoustic principles: porous materials tend to perform better at higher frequencies, while effective absorption at low frequencies requires thicker, denser materials. Therefore, the design of acoustic panels should carefully consider the target frequency range to achieve optimal sound absorption performance.

5. Conclusion

The results of this study demonstrate that the sound absorption testing device based on a simple impedance tube system was successfully designed and constructed according to the specified configuration, using a 4-inch-diameter PVC tube measuring 100 cm, one speaker, and two microphones. This configuration enables sound pressure measurements at two points, allowing the analysis of incident and reflected waves within the tube. Experimental testing showed that the device is capable of consistently detecting differences in sound pressure levels between conditions without and with material samples, with significant variations observed particularly at higher frequencies (1000 Hz), indicating that the impedance tube system performs effectively and provides representative results. The tested material, rockwool, exhibited the highest sound absorption coefficient (α = 0.97) at 1000 Hz, while at low to ủɧǫ frequencies the absorption coefficient remained relatively low (0.05–0.11). This confirms that rockwool is highly effective at high frequencies for sound absorption but less effective at lower frequencies, without additional modifications such as increased thickness or material combinations. For future research, it is recommended to perform periodic calibration to maintain measurement accuracy, extend the testing frequency range to include lower (<125 Hz) and higher (>1000 Hz) frequencies for a more comprehensive analysis, investigate variations in material thickness and types to understand their influence on absorption performance better, and conduct measurements in a controlled or soundproof environment to minimize external noise interference and improve data validity.

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