[1.]Kristián PÁSTOR, [2.]Miriama PIŇOSOVÁ, [3.]Miroslav BADIDA

MEASUREMENT OF THE SOUND ABSORPTION COEFFICIENT USING AN IMPEDANCE TUBE

[1-3.] Technical University of Košice, Faculty of Mechanical Engineering, Department of Process and Environmental Engineering, Park Komenského 5, 042 00, Košice, SLOVAKIA

Abstract: In the present age, the acoustic properties of materials play an increasingly important role in the design and solution of passive control of unwanted noise in several industries. Knowing these properties before their actual application in practice is extremely important. There are various methods and approaches to evaluation and various ways to examine these properties. For this research, we selected 9 types of materials, which were evaluated in terms of the analysed acoustic properties at different thicknesses (2 - 60 mm) with diameters of 30 and 60 mm as separate single-layer, but also as a two-layer and three-layer sandwich of materials (a total of 61 variants of arrangement). The analysis was performed on the basis of measurements for which an impedance tube was used, and the analysed acoustic property was the sound absorption coefficient α (-). Measurements were performed in the frequency range from 100 Hz to 6300 Hz. We compared the results of measurement in terms of changes in the acoustic properties with varying thicknesses and frequency range.
Keywords: impedance tube, measurement, sound absorption

1. INTRODUCTION

Sound absorption represents the amount of energy of sound pressure waves dissipated into mechanical vibrational energy and thermal energy. In 1920, Sabine, Paul Earls summarized the principles of this phenomenon as follows: "Qualitatively, the theory of sound absorption is simple. The decomposition forces, by which sound energy is converted into heat, are introduced in two ways. The flexibility of the reflecting surface as a whole or in large units of the surface under the alternating pressure of the sound wave induces damping forces which dissipate the sound energy." In 1937, 17 years after the establishment of the Sabine Acoustic Laboratories in Riverbank, Illinois, similar facilities, and test rooms were set up in Turin, Italy at the Galileo Ferraris National Electrotechnical Institute, Istituto Nazionale di Ricerca Metrologica (INRiM) [1]

The acoustic properties of materials play an increasingly important role today. This is due to the significant growth of the automotive industry and the need to increase quality due to market competitiveness and also due to growing traffic noise. This is why a number of new acoustic materials with sound-insulating properties are being discovered and developed all the time. These materials are used for passive sound regulation in the interior design of automobiles, factories, workshops, residential buildings, noise barriers, etc. to prevent unwanted noise. Determining their acoustic properties is therefore extremely important. [2] [3]

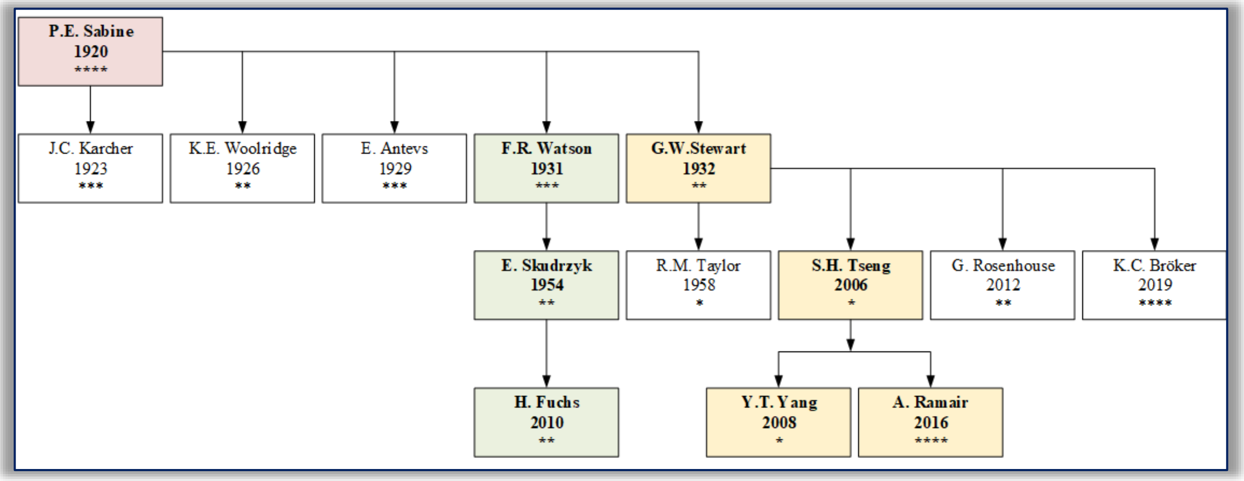


Figure 1. Flowchart showing selected articles that are considered original, beginning with P. E. Sabine (1920) [4–13]

Research in this area seeks to control and minimize the sounds that occur in machines, cars, homes and other places. There are a large number of studies and research experiments that are trying to develop and discover new materials that can be used in various acoustic projects. Sound absorption is one of the most important physical phenomena studied in the analysis of these materials [14]

Table 1. Eligibility criteria for forward and backward citation. Studies ranging from a very high relevance to low relevance (see Figure 1)

Rating	Relevance	Publisher
****	Very High	Relevant Journal or High Impact Report (e.g. CCC, Web of Science, SCOPUS)
***	High	Journal, Report or Thesis
**	Medium	Book Publications
*	Low	Conference

Various synthetic materials have excellent acoustic properties, but their price and harmful effects on the environment must be taken into account. Bhingare N.H. [15] describes the properties of natural fibres and waste (recycled) material. Natural materials are an effective alternative to synthetic ones due to their low cost and lower environmental impact. Waste material present in the environment, such as rubber crumbs from tires, waste wood etc., can be used with acoustic applications. This is emphasized in current research of natural fibrous materials, such as jute, kenaf, kapok and coconut fibres, fibres from palm and sugar cane, corn husk fibre and their acoustic performance is being researched. It was concluded that the properties of these natural materials can be effectively used for acoustic applications. The possibilities of using recycled natural or synthetic polymers from waste rubber in the production of acoustic materials for its good acoustic properties was studied by Xinwu X. [16]

Peng, C. [17] presents the use of an impedance tube with two microphones to measure impedance at low frequencies. He argues that accurate and reliable prediction of noise in the vehicle interior would be an important step to improve the design of body panels and trim for the development of a quieter vehicle. It was found that the location of the microphones is crucial for the accuracy of the measurement. The analytical results of the study showed that the ideal placement of the microphones is important both in their placement and in the distance from the tested material to the nearest microphone – a quarter of the wavelength.

Niresh J. [2] addressed, in detail, various methods of measuring the acoustic characteristics of materials used to control noise in automobiles. He states that one of the factors influencing the choice of car is noise. Noise control in the car is essential because among other things it increases passenger comfort, making long-distance travel less tiring.

Akiwate D. C. [18] investigated the acoustic properties of porous materials produced by 3D printing. The results of the study suggest that the sound absorption coefficient in layered porous materials produced by the 3D printing method can be adjusted to the desired frequency range by changing the filling percentage.

Tan W. H. [19] describes a process for manufacturing an impedance tube for measuring the sound absorption coefficient. The impedance tube was designed and manufactured in accordance with ISO 10534-2: 1998 with a diameter of 114.3 mm and a length of 1.42 m for the frequency range from 60 Hz to 1800 Hz with three microphones. Suhanek M. [20] also describes a process for manufacturing an impedance tube. The authors also analysed the acoustic properties of materials by means of an impedance tube in these publications.

2. DESCRIPTION OF THE MEASUREMENT METHOD AND SAMPLE PREPARATION

The impedance tube was originally invented to detect the speed of sound in gases. It was later used to demonstrate standing sound waves. The impedance tube should be straight along its entire length with a constant cross-section and rigid, smooth, non-porous walls without any holes or notches except for the microphone positions. The walls of the tube should be heavy and thick so that they are not vibrated by an audible signal and so that they do not show any vibrational resonances in the operating frequency range of the tube [2].

The measurement of the sound absorption factor α (-) was performed using a BSWA SW466 impedance tube in a configuration with two microphones using the transfer-function method according to the STN EN ISO 10534-2 standard. At one end of the tube there is a speaker with a diameter of 4 inches (101.6 mm) and 20 watts power. The operating frequency of the speaker is from 20 Hz to 8000 Hz. At the opposite end is a sample holder designed for samples with a diameter of 30, respectively. 60 mm and thickness from 0 - 100 mm. In this configuration, the tube has three microphone placement options. Their location depends on the frequency range we want to measure. Microphone positions 1 and 2 are used to measure sound absorption in the frequency range 400 - 2500 Hz. The distance between positions 1 and 2 is 45 mm and the distance of position 2 from the test sample is 35 mm. Positions 0 and 2, which are 170 mm apart, are used to measure sound absorption in the frequency range from 100 - 800 Hz. With this form of tube connection, it is possible to measure the sound absorption coefficient in the frequency band from 100 - 2500 Hz. Other components of the measuring technology are an MC3242 4-channel analyser for data collection with 4 BNC input channels with an ICP power supply and 2 BNC output channels (20 Hz - 20 kHz), measuring power amplifier PA50 (50W) for powering the speaker in the impedance tube, 1/4 inch IEC61672 class 1 microphone with ICP preamplifier and 50 mV/Pa sensitivity, PC with VA-Lab4 software for information evaluation and tube control, cabling (Figure 3).

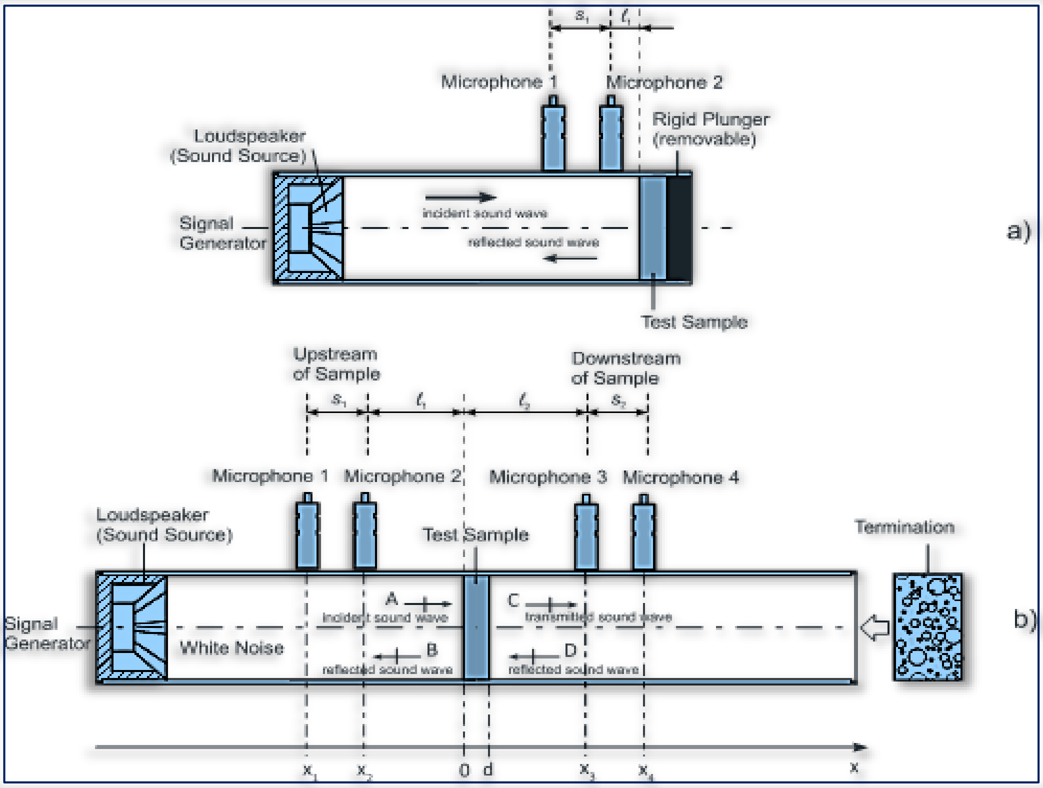


Figure 2. Schematic of the SW466 impedance tube, a) transmission method with two microphones, b) transmission method with four microphones

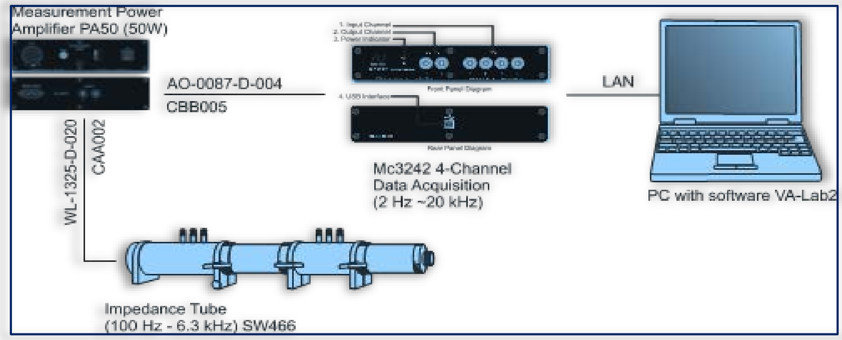
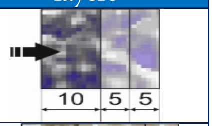
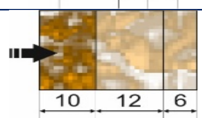
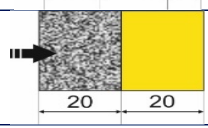
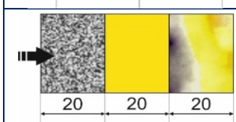


Figure 3. Wiring diagram of measuring technique for measuring the sound absorption factor α (-)

Prior to the start of each measurement, the following parameters of the microclimatic conditions were recorded: dry air temperature, relative humidity and air flow rate. These parameters were measured with a Testo 435 multifunction measuring instrument with a three-function probe. The values of individual parameters were measured after stabilization of the device, at least after 15-30 min.

Table 2 shows a sample of samples of materials used for the experiment. All samples had the same diameter, 30 mm or 60 mm, which corresponds to the inner diameter of the tube d = 0.030; 0.060 m. The thickness of the samples varied (t = 2 - 60 mm). The method of arranging the layers in the samples is indicated in the table.

Table 2. Display of examined samples

Material of sample	Thickness (mm)	Diameter (mm)	Arrangement of layers
Propylat	10 15 20	30 / 60	
Triflex	10 22 28		
Recycled rubber Nobasil	40		
Recycled rubber Nobasil Ecomolitan	60		
Note ➡ direction of sound waves from source			

3. PROCESSING, COMPARISON AND EVALUATION OF MEASUREMENT RESULTS

In this part of the paper we will present the evaluation and comparison of the results of measurement of the sound absorption coefficient α (-) for selected materials. To evaluate the damping properties of selected materials, the dependence of the sound absorption coefficient on the frequency range was considered from 100 to 6300 Hz. The sound absorption coefficient (α) is a dimensionless number ranging from ‹0,1›. The closer the value of the coefficient is to the number 1, the better the sound absorption of the material. Six measurements were performed for each sample, from which the average value was determined.

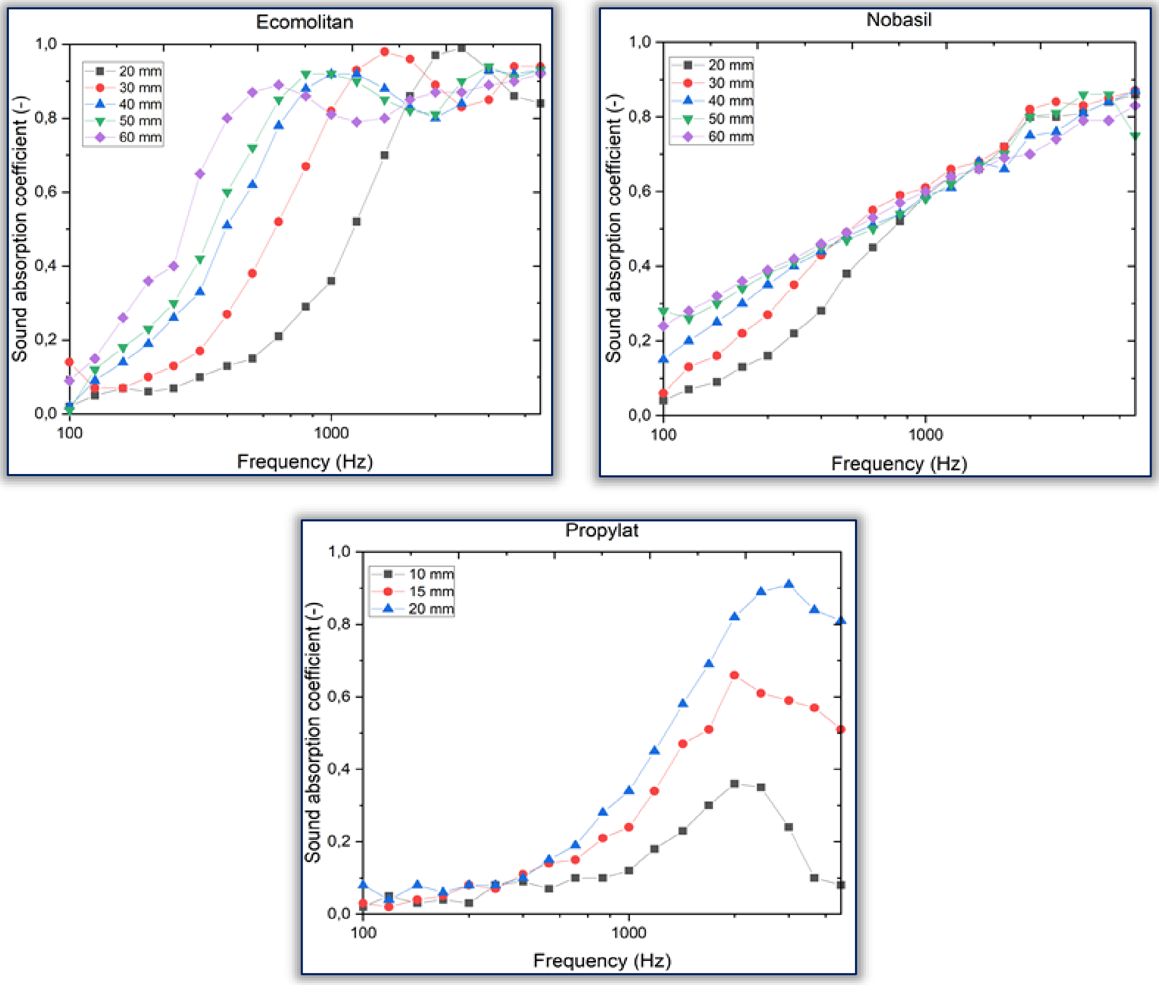
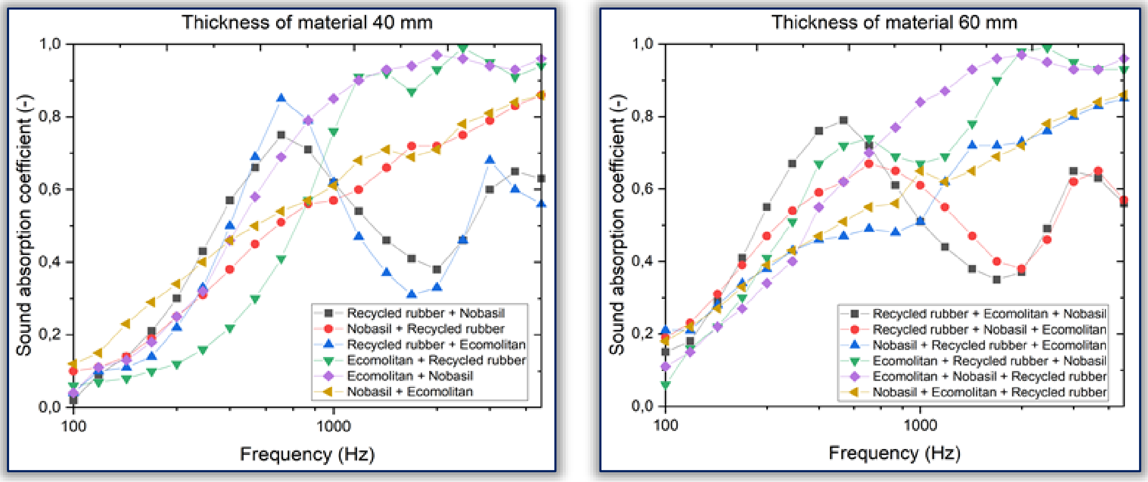


Figure 4. Demonstration of sound absorption coefficient values α (-) for single-layer materials



a) b)

Figure 5 Example of comparison of values of the sound absorption coefficient α (-) for a) two-layer and b) three-layer materials

The results of measurements of single-layer acoustic materials show that the worst values of the investigated materials show at low frequencies from 100 to 315 Hz (α = 0.00 - 0.35), of which 19 (70.37%) are cases at a frequency of 100 Hz. The best values of α > 0.5 range in the wider frequency spectrum from 800 – 6300 Hz (α = 0.50 - 0.99). The best values of damping α > 0.86 were achieved in the same way after seven samples at frequencies of 2500 and 6300 Hz. For the materials Ekomolitan, Nobasil and Propylat, it is clear from the measurement of the sound absorption coefficient that the value of this coefficient depends on the thickness of the material. As the thickness of the material increases, the sound absorption coefficient increases. In seven cases (25.92%) of the examined materials Nobasil and Ekomolitan with sample thickness of up to 30 to 60 mm, the minimum / maximum values for the coefficient α were reached at frequencies of 100 (α = 0.02-0.24) / 6300 Hz (α = 0.83-0.93)

The combination of two-layer materials showed that the worst values of sound absorption are achieved using the investigated materials at frequencies from 100 Hz to 160 Hz (α = 0.02 - 0.44), of which up to 24 (88.88%) cases at a frequency of 100 Hz. The best values of α > 0.75 were measured mainly in the middle frequency band 315 - 800 Hz, of which 15 samples (55.55%) had α > 0.94 at the frequency of 315, or 400 Hz. The results of the experiment further show that the resulting values of the sound absorption coefficient are influenced not only by the combination of materials, i.e. what materials it was composed of, but also by the arrangement of these materials with respect to the direction of sound propagation. In the case of the Recycled Rubber + Nobasil sandwich system, the lowest value of the sound absorption coefficient was at a frequency of 125 Hz and the highest α = 0.86 was at a frequency of 6300 Hz. In general, we can say that using this material with Nobasil is closer to the sound source, reaches a higher value across the whole frequency range compared to the opposite side of the examined sample. In the reverse arrangement of these materials, the highest achieved value was α = 0.75 at a frequency of 630 Hz. In this example, we can see that by changing the arrangement of the materials in the layers, their sound-absorbing properties also change, both in terms of how good sound absorption they provide, and also at what frequencies they are most effective.

The results of the evaluation of materials arranged in three layers show that, regardless of the arrangement of the layers of materials, all variants achieve the lowest values for the sound absorption coefficient at a frequency of 100 Hz. The best values, however, vary depending on the layout variant.

The highest value, α = 0.99, was achieved by the combination of Ekomolitan + Recycled rubber + Nobasil at a frequency of 3150 Hz. It can be seen in Figure 5 that N + R + E, or N + E + R have stable acoustic properties and there is a steady increase in the sound absorption coefficient with increasing sound frequency. They do not reach the highest values of α, but their properties are more even in comparison with other arrangements of the material in the sandwich system. These results therefore show, as with two-layer sandwich materials and three-layer sandwich materials, that it's not only the material composition of the sandwich that is important, but the arrangement of materials in layers can also significantly affect the properties of this material and thus its use in practice as acoustic insulation material. In general, therefore, it can be stated that that from the point of view of sound absorption, by creating sandwich materials composed of suitably selected base materials and arranging them suitably, we can manipulate the properties of these materials in different frequency bands very well and thereby obtain a suitable insulating material for specific purposes. According to the measured results, it can be stated for the sound absorption coefficient that the thickness of the analysed materials had an effect on the value of the coefficient in three of the seven cases in the evaluation of single-layer materials. The creation of sandwich materials significantly affected the value of the coefficient and the properties of the materials in different frequency bands. In the case of sandwich materials, the arrangement of the materials with respect to the direction of sound propagation played a role. By creating sandwich materials distributing the suitably, we can manipulate the sound absorption properties of these materials at different frequencies very well and thereby obtain a suitable insulating material for specific tasks. It is important to note that the results of the experiment performed apply to selected single-layer and sandwich materials that were used for this experiment.

Acknowledgement

This work was supported by the projects of the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic project UNIVNET No.0201/0004/20 and with support from the project titled KEGA No. 009TUKE-4/2021: Implementation of the latest knowledge from recycling technologies for material recovery of product components at the end of their life cycle.

References

[1] A. Schiavi, A. Prato, "Evaluation of sound absorption: An experimental comparative study among reverberation room, impedance tube and airflow resistivity-based models," 2019.
[2] J. Niresh, S. Neelakrishnan, S. Subharani, T. Kannaian, and R. Prabhakaran, "Review of acoustic characteristics of materials using impedance tube," ARPN J. Eng. Appl. Sci., vol. 10, no. 8, 2015.
[3] B. Arunkumar, S. Jeyanthi, "Design and analysis of impedance tube for sound absorption measurement," ARPN J. Eng. Appl. Sci., vol. 12, no. 5, 2017.

[4] P. E. Sabine, “The absorption of sound by rigid walls,” Phys. Rev., vol. 16, no. 6, 1920, doi: 10.1103/PhysRev.16.514.
[5] J. C. Karcher, “A method for the measurement of sound intensity,” Sci. Pap. Bur. Stand., vol. 19, 1983.
[6] E. Skudrzyk and E. Skudrzyk, “Grundsätzliches zur Raumakustik,” in Die Grundlagen der Akustik, 1954.
[7] H. Fuchs and H. V. Fuchs, “Schallabsorber in der Raumakustik,” in Schallabsorber und Schalldämpfer, 2010.
[8] K. C. Bröker, “An overview of potential impacts of hydrocarbon exploration and production on marine mammals and associated monitoring and mitigation measures,” Aquat. Mamm., vol. 45, no. 6, 20198
[9] A. Ramiar, A. H. Mahmoudi, Q. Esmaili, and M. Abdollahzadeh, “Influence of cathode flow pulsation on performance of proton exchange membrane fuel cell with interdigitated gas distributors,” Energy, vol. 94, 201688.
[10] F. R. Watson, Bibliography of Acoustics of Buildings. Committee on Acoustics of Buildings, 1931.
[11] R. M. Taylor, The Emporia State. Research Studies. Kansas: Kansas State Teachers College of Emporia, 1958.
[12] S. H. Tseng, “Fluidic oscillator design for water removal enhancement in a PEM fuel cell,” 2006.
[13] Y. Yang and S. Yang, “Implementation of a third-order monotonic upwind-biased scheme into the kiva code for engine flow simulation,” 2008
[14] C. V. M. Rosely, R. H. A. Silva, T. M. Linhares, C. M. Rocha, “The impedance tube construction and acoustic absorption study applied materials inside vehicles,” in 41st International Congress and Exposition on Noise Control Engineering 2012, INTER-NOISE 2012, 2012, vol. 2.
[15] N. H. Bhingare, S. Prakash, V. S. Jatti, “A review on natural and waste material composite as acoustic material,” Polym. Test., 2019, doi: 10.1016/j.polymertesting.2019.106142.
[16] X. Xu, H. Wang, Y. Sun, J. Han, R. Huang, “Sound absorbing properties of perforated composite panels of recycled rubber, fiberboard sawdust, and high density polyethylene,” J. Clean. Prod., vol. 187, 20188.
[17] C. Peng, D. Morrey, P. Sanders, “The measurement of low frequency impedance using an impedance tube,” J. Low Freq. Noise Vib., vol. 17, no. 1, 1998
[18] D. Akiwate, S. R. Mohan, B. Venkatesham, S. Suryakumar, “Acoustic characterization of additive manufactured layered porous materials,” 2019.
[19] W. H. Tan, R. Ahmad, N. H. Zunaidi, R. Daud, and E. M. Cheng, “Development of an Indigenous Impedance Tube,” Appl. Mech. Mater., vol. 786, 2015
[20] M. Suhanek, K. Jambrosic, and H. Domitrovic, “Student project of building an impedance tube,” 2008

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665