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Evaluation of White Noise's Acoustic Performance on some Industrial Insulating Materials

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Abstract: *The assessment of white noise's acoustic performance on some industrial insulation materials is presented in the current work. The standing wave method is used to measure and evaluate the acoustic properties of sound-absorption materials, including their acoustic impedance and absorption coefficient. The signal processing method was combined with a burst of white noise. The technique is founded on the straightforward harmonic motion equation, however, the variable used instead of time was distance. The measurement enables for a reasonable period of time, 1 cm of distance, with resolutions down to 5 Hz in frequency. Nonetheless, these characteristics of the distances and the resolution of the frequency employed do have an impact on the outcomes by the responses of the signals that are generated at each measurement period. The results from the analyzer reveal a wide range of data details describing the enhanced acoustic impedance and absorption coefficient chart of evaluated samples.*

Keywords: *Acoustic Impedance, Sound, white noise, Assessment, Absorption coefficient.*

1. INTRODUCTION

There are many vibrating objects on earth that control how longitudinal pressure waves in the air moves. The energy of sound creates a sound wave or mechanical movement. The energy must leave the sound source and move outward. The medium, such as the air, transmits the mechanical wave. The ear, is the detector that picks up the wave [1]. An alternative method to the reverberant room method that is less expensive and time-consuming is required to characterize the materials' capacity to absorb sound. Sound absorption is a technique for preventing sound waves from penetrating a space. Sound transmission loss, which is measured by the decibel difference between incoming and absorbed sound, is one of its characteristics. A single microphone positioned at a pre-set location can be used to do this type of assessment, the level being observed and recorded, and proper time averaging being used at each location [2]. Acoustic materials are essential in noise-reduction strategies like airborne sound silencers or machinery housings. The acoustic materials used are often what give an industrial noise control solution its strength. The incident acoustic energy on the object is converted into transmitted, reflected, and energy-loss acoustic energy. The ratio of energy loss plus transmitted energy to incident energy is known as the acoustic absorption coefficient. The proportion of reflected acoustic energy to incident energy is known as acoustic reflectivity. The ratio of energy transferred to energy incident is known as acoustic transmissibility [1]. The absorption coefficient is a way of measuring how well a material can block out sound. The absorption coefficient describes how much energy a surface absorbs compared to the energy that is incident on it. The absorption coefficient could be anywhere between O and 1. When the value is O, all incident sound energy is reflected, and when it is 1, all energy is absorbed. The absorption coefficient's value is influenced by frequency [3]. The standing wave technique was used to evaluate the acoustic properties of sound-insulating materials, including acoustic impedance and absorption coefficient. Using simple harmonic motion formula as the foundation for an algorithm where the variable is distance instead of time. This method measures the acoustic impedance of industrial sound absorption materials with frequency resolutions of 5 Hz in a respectably brief period of time using an impedance tube with a moveable single microphone and a white noise generator [4]. [5] examined the sound-absorbing properties of recycled polyester nonwovens to substitute with more conventional materials like glass wool and Rockwool. The sound absorption coefficient of recycled polyester nonwovens was determined by comparing the absorption energy rate to the energy of incidence using a two-microphone impedance measurement tube. [6] observed how the silica aerogels' thermal and acoustic parameters for performance were impacted by the granule size. Given the characteristics of the sample, a Hot Plate setup is used to measure the thermal conductivity (λ), which establishes an appropriate methodology. Conversely, the transmission loss (TL) is evaluated in a typical impedance tube at normal incidence. The results demonstrated that performance is granule size dependent, with tiny granules (granule sizes between 0.01 and 1.2 mm) having the highest density and most efficient performance in terms of thermal and acoustic characteristics. Tiny granules had a TL of 13 dB at around 6400 Hz and a thickness of 20 mm, while λ varies between the 19–22 mW/mK range at 10°C. Also, Due to an increasing interest in employing insulation for recycled and environmentally friendly materials, basalt natural fiber insulating panels were examined to evaluate their thermal and acoustic qualities. Thermal conductivity was assessed using a heat flow meter device, and the acoustic absorption coefficient was determined using an impedance tube. These values fall within the range of 0.030-0.034 W/mK. The outcomes were contrasted with conventional approaches that had inferior mechanical resistance but had a similar chemical makeup, like the rock wool and glass wool panels [7]. In the current work, white noise generators will be utilized to test the acoustic impedance of several a number of industrial insulation materials instead of sine waves or a third of an octave, in order to evaluate their sound insulation qualities with white noise.

2. MATERIALS AND METHODS

Impactodan, PN70, Ekla, National Instrument (NI) LabVIEW, NI 9263, 9234, Impedance tubes, a loudspeaker, a moveable microphone, a desktop computer, a meter rule, and the NI CDAQ 9174 for data collecting and processing were employed in the development of the LabVIEW white noise generator application. The acoustic characteristics of the material can be determined using this data, which can then be used to calibrate and validate computational techniques for predicting the sound insulation capabilities of multi-layer systems [4]. Using defined methods, the normal incidence absorption coefficients of sound absorbing materials are measured. One of these established techniques for determining the standard incident absorption coefficients is Kundt's tube, widely referred to as a standing wave or impedance tube: in relation to stationary waves [8], as well as transfer-function techniques [9]. The microphone's side wall attachment prevents it from obstructing the sound field inside the tube while implementing the transfer function technique. Unfortunately, complications could arise because there are not enough microphone locations and the microphones are too close together. the separation between microphones should be equal to or greater than five times the diameter of each microphone, according to [8]. Frequency is another factor that affects how far apart the microphones should be to make accurate measurements (that is, it is reduced with an increase in frequency). Misaligned microphone phases and errors in determining the precise location of the microphone and sample are other potential problems [10]. Comparing the single moveable microphone method to the two- to the three-microphone method and the reverberation chamber, which both offer a quick broadband alternative, reveals that it has the distinct advantage of avoiding the somewhat laborious calibration procedure required for transfer function measurements. The normal specific impedance and the normal incidence absorption coefficient of a variety of sound absorbing materials are measured using impedance tubes [4].

2.1. Sample descriptions

A Portuguese company called Pronorma that specializes in Acoustic Sampling of Structures provided the materials for this study

Table 1: showing the material samples and their applications.

PN70 	**Materials:** Resin and Rockwool **Applications:** Thermal and acoustic insulation solution.
Ekla 	**Materials:** Composite material: Mineral coating and Volcanic Rockwool. **Applications:** Those who have high expectations for local sound absorption, such as: • Open office • Call centre • Collective entertainment • Venues for education
Impactodan 	**Materials:** Plastic material (Polyethylene) **Applications:** Percussion sounds

The experimental setup is shown schematically in "Fig. 1." In investigations with an impedance tube utilizing the standing wave ratio approach [9], one microphone was used, and circular samples were placed at one of the ends of the tube. A white noise source of sound is placed at one end of the tube and ends at the opposite end, which contains the test sample when applying the standing wave technique. The microphone travels through the entirety of the tube, beginning at the loudspeaker end and terminating at the sample end after the sound has been launched, covering a distance of 1 cm for each and every measurement.

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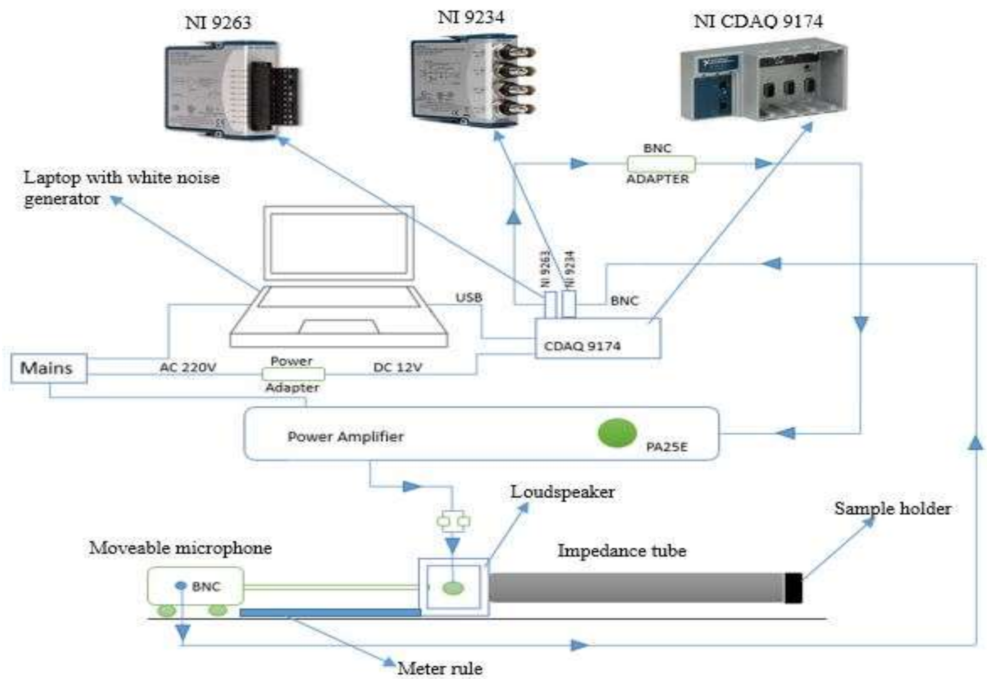

Fig. 1. *Conceptual block representation of the Experimental Setup,*

The developed white noise generator records the location and strength of the first extrema, as well as the succeeding minima and maxima. Employing this information, the samples' specific sound impedance and acoustic absorption coefficient may be determined. This is performed by scanning the entire tube length at different frequencies with 5 Hz resolution, 1 cm apart, from 0 Hz to 6500 Hz. The maximum frequency is reported to be 6500 Hz, which is obtained by employing a frequency resolution of 5 Hz and for every 1 cm measurement of the sample evaluated. The 5 Hz resolution permits measurements to be obtained for a variety of frequencies of 5 Hz to 6500 Hz every single cm the microphone travels. This suggests that measurements can be taken for any resolution specified for the testing sample; for example, if a resolution of 2 Hz is chosen for the application, then measurements could be taken for each 2 Hz and its addition up to the greatest frequency allowed. The needed cm and 5 Hz were chosen to limit any aliasing that might interfere with the results.

Aliasing happens when a signal is sampled at a rate that is inadequate to capture the variations in that signal. This means that some undesired components that were missing from the sampled original signal are now present in the rebuilt signal. When the sampling frequency is either low or too little in comparison to the signal being sampled, signal frequencies may infrequently overlap, resulting in aliasing [11].

2.2. Measurement of the Sound absorption Impedance in a Standing Wave Tube Using White Noise

White noise is a scientifically random signal with a homogeneous power distribution across its frequency range. This implies a flat power waveform density, which means that any frequency within a fixed bandwidth, meaning that any frequency within a constant bandwidth—the space between the upper and lower frequencies in an uninterrupted bandwidth of frequencies measured in Hertz—will produce same amount of power [4]. The white noise generator was created with NI LabVIEW, which was also used to generate the sound, collect data, and process the data to determine the sound impedance and absorption coefficient of the examined samples. The frequency bandwidth simplifies the explanation of the signals by explicitly identifying them as harmonics. The spectrum of frequency of a time-domain signal, which likewise represents an amplitude against a time signal, can be expressed as a signal in the frequency domain using the Fast Fourier Transform (FFT). The FFT "breaks down" a cycle of random harmonics or signals into sine wave with frequency and amplitude components.

The first step in finding the Sound Impedance in an Impedance tube is to define the Standing Wave Pressure Ratio SWR.

$$SWR = \frac{P_{max}}{P_{min}} = \frac{A + B}{A - B} \tag{1}$$

where P_{max} is the pressure maximum of the standing wave in the tube, P_{min} is the pressure minimum and?

$$R = \frac{B}{A} = \frac{SWR + 1}{SWR - 1} \quad (2)$$

is the ratio of the amplitudes of the incident and reflected waves?

[4] used an innovative way to represent a standing wave in a tube. The experimental data for a harmonic signal collected across the length of an impedance tube is shown in "Fig. 2." below.

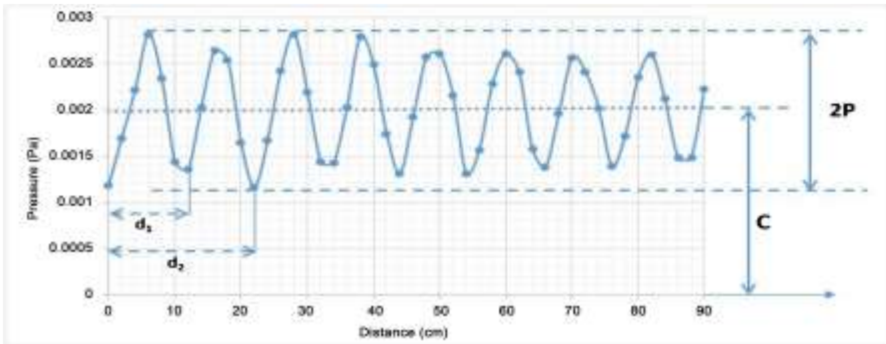

Fig. 2. *Plot of amplitude against distance for a 1700 Hz standing wave [4]*

The mathematically equivalent harmonic waveform to the sine function in the time domain is:

$$P(t) = P \cdot \sin(\omega t + \alpha) + C \quad (3)$$

where the wave's angular frequency is ω, the offset mean pressure is C, and the phase angle is α. The last two values can be found by:

$$C = \frac{P_{max} + P_{min}}{2} \quad (4)$$

$$\alpha = 1 - \left(\frac{SWR - 1}{SWR + 1}\right)^2 = 1 - R^2 \quad (5)$$

The waveform in "Figure.2" is suggested to be written as:

$$P(d) = P \cdot sin(\hat{\omega} d + \hat{\alpha}) \quad (6)$$

Since each harmonic spectrum component may be represented as a sinusoidal function of distance d rather than time t, and because each white noise spectral component has a pattern comparable to the harmonic waveform (after FFT),

Equation (3) and (6) are comparable, therefore the following results:

$t(s) \rightarrow d(m)$
$\omega(rad \cdot s^{-1}) \rightarrow \hat{\omega}(rad \cdot m^{-1})$
$\alpha(rad) \rightarrow \hat{\alpha}(rad)$
The values for $P, C, \hat{\omega}$ and $\hat{\alpha}$ are extracted with the assistance of LabVIEW software, where:

$$P = \frac{P_{max} - P_{min}}{2} \quad (7)$$

$$P_{max} = C + P \quad (8)$$

$$P_{min} = C - P \tag{9}$$

The phase angle was taken into account when calculating the distance d_1 of the initial minimum from the sample under investigation:

$$d_1 = -\frac{\hat{\alpha}}{\hat{\omega}} + \frac{3\pi}{2\hat{\omega}} \tag{10}$$

If $d_1 < 0$, the answer to "(10)" needs to be changed to:

$$d_1' = d_1 + \frac{2\pi}{\hat{\omega}} \tag{11}$$

due to the fact that a negative distance is illogical. It is possible to calculate the wavelength and the distance d_2 between the sample and the second minimum $\lambda = 2(d_2 - d_1)$; hence:

$$d_2 = \begin{cases} d_1 + \frac{2\pi}{\hat{\omega}}, & d_1 > 0 \\ d_1' + \frac{2\pi}{\hat{\omega}}, & d_1 < 0 \end{cases} \tag{12}$$

The real and imaginary parts of the acoustic impedance Z_n can therefore be determined from the equations that result from the previous equation, which gives $d_1$and d_2.

$$\mathrm{Re}\left(\frac{Z}{\rho c}\right) = \frac{1 - R^2}{1 + R^2 - 2R\cos(\Delta)} \tag{13}$$

$$\mathrm{Im}\left(\frac{Z}{\rho c}\right) = \frac{2R\sin(\Delta)}{1 + R^2 - 2R\cos(\Delta)} \tag{14}$$

where Δ is the phase angle between the incident and reflected sound pressure, c is the speed of sound in the tube, and ρ is the air density?

$$\Delta = \left(\frac{4d_1}{\lambda} - 1\right)\pi = \left(\frac{2d_1}{d_2 - d_1} - 1\right)\pi \tag{15}$$

Finally, the Acoustic Impedance in rayls may be calculated from "(13)" and "(14)" using the Real and Imaginary components of the Acoustic Impedance.

$$Z = \rho c \sqrt{\mathrm{Re}^2\left(\frac{Z}{\rho c}\right) + \mathrm{Im}^2\left(\frac{Z}{\rho c}\right)} \tag{16}$$

3. When using white noise, the assessment is performed while the impedance tube (which incorporates a moving microphone) is moved from 90 cm to 0 cm from the sample. As shown in the Results and Analysis section, the LabVIEW application applies the above-mentioned technique to post-process the data and automatically calculate the sound Impedance of the sample materials as a function of frequency with a significantly increased frequency resolution.

4. RESULTS AND ANALYSIS

The assessment of acoustic measurements was performed using an impedance tube and a set-up with a single movable microphone. This turns sound pressure into electrical impulses, which were recorded, shown on the built application, and then analyzed to look at the relationship and effect between the tested materials' acoustic impedance and them. The white noise generator simply executes one series of measurements to acquire the pressure minima and maxima at pre-defined frequencies ranging from 0 Hz to 6500 Hz with a resolution of 5 Hz and distances ranging from 0 to 90 cm. Impedance measures how easily a sound wave can travel between two media.

The sound impedance at certain frequencies reveals how much sound pressure is generated at that frequency by air vibration of the molecules of that particular sound medium. This implies that as a wave reaches a boundary with another material, the amount of sound reflected and transmitted is determined by the sound impedance of the substance. As a result, as acoustic impedance increases, the sample's absorption coefficient drops. That is, a material with a high acoustic impedance will not allow sound energy to pass through the medium, whereas a substance with a low acoustic impedance will not impede sound energy as much.

PN70

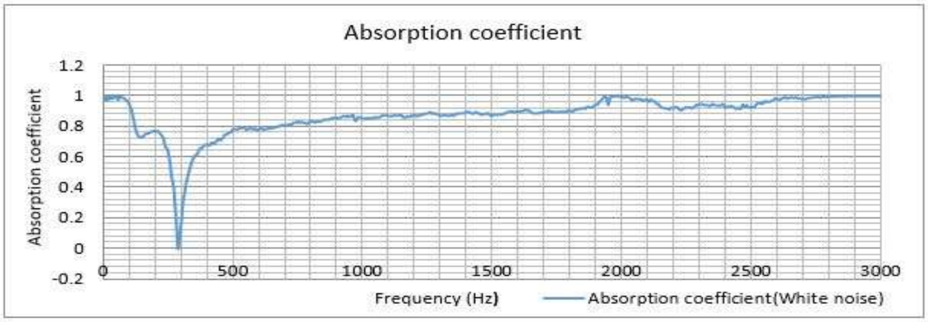

Fig. 3. *Absorption coefficient for PN70 sample utilising white noise with 5 Hz resolution*

The absorption coefficient for the PN70 sample is shown decreasing from 1 to 0 at frequencies between 0 and 299 Hz, then gradually increasing from 300 Hz to 500 Hz to attain an absorption coefficient value of 0.76, and then increasing from 0.8 to 1 at frequencies between 500 Hz and 2750 Hz in "Fig. 3." This sample has good sound absorption properties because the sound wave is absorbed gradually and continuously up to the absorption coefficient value of 1. The density and thickness of the material might be cited as important factors influencing absorption capability.

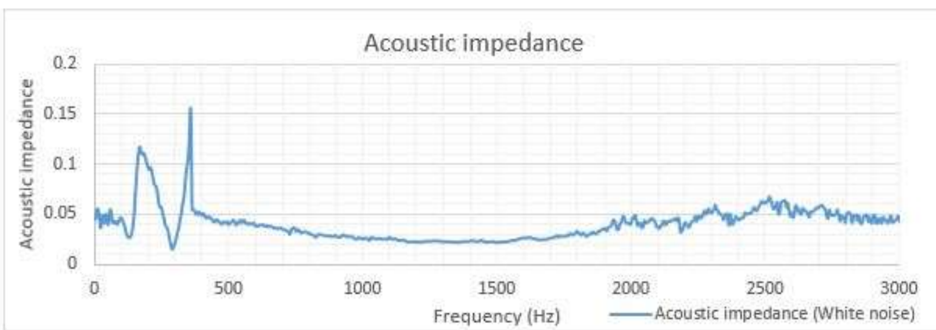

Fig. 4. *Acoustic Impedance for PN70 sample employing white noise with 5 Hz resolution*

According to "Fig. 4," the PN70 sample's acoustic impedance yields the opposite of the absorption coefficient, indicating that the sample has a low sound impedance. The majority of the sound energy can be transferred by the sample.

4.1. Ekla

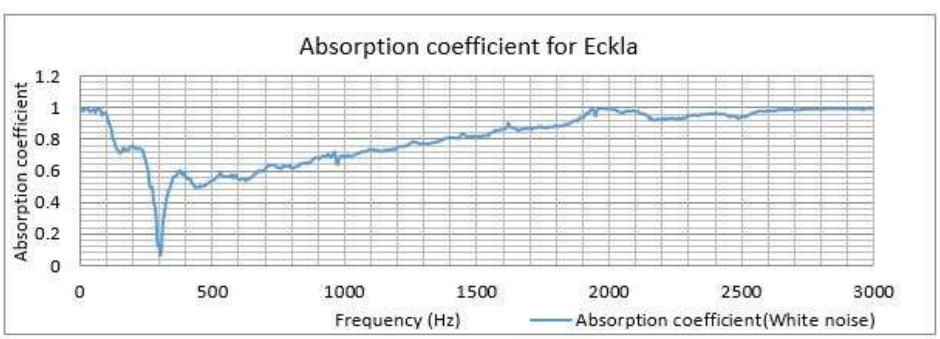

Fig. 5. *Absorption coefficient for Ekla sample utilising white noise with 5 Hz resolution*

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The absorption coefficient for the Ekla sample is depicted decreasing from 1 to 0.4 at frequencies 0 to 300 Hz, then gradually increasing from 500 Hz to 300 Hz to reach a value of 0.6 with fluctuations, and then increasing from 0.6 to 1 at frequencies 650 Hz to 1950 Hz while still fluctuating in "Fig. 5." The sample absorbs the sound wave, but with fluctuations up to the absorption coefficient value of 1. This sample has good sound absorption capabilities. It is possible to argue that the density and thickness of a substance have a substantial impact on how well an absorbent operates.

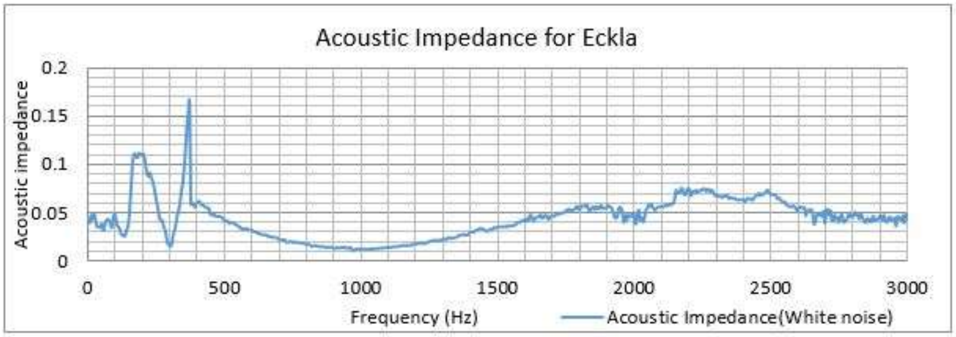

Fig. 6. *Acoustic Impedance for Ekla sample utilizing white noise with 5 Hz resolution*

Furthermore, the Ekla sample's sound impedance, depicted in "Fig. 6." below, yields a pattern that is the inverse of the absorption coefficient, indicating that the sample has a moderate resistance to acoustic. As a result, the sample transferred the majority of its sound energy, and the fluctuation was apparent.

4.2. Impactodan

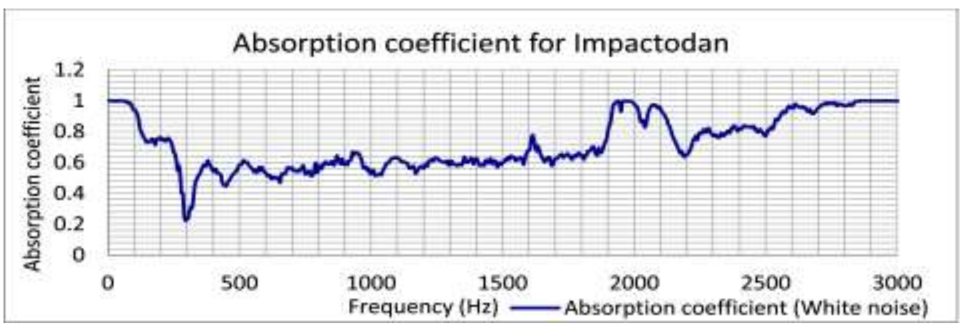

Fig. 7. *Absorption coefficient for Impactodan sample utilising white noise with 5 Hz resolution.*

When compared to the other samples tested, the Impactodan sample shown in "Fig. 7." exhibited the commonly observed reversed action. It then steadily rises with a lot of variations from 295 Hz to 2800 Hz, from which the analysis may be an indication of noise measurement. Furthermore, a visual examination of the Impactodan sample reveals that it is one-sixth the thickness of the other samples being examined.

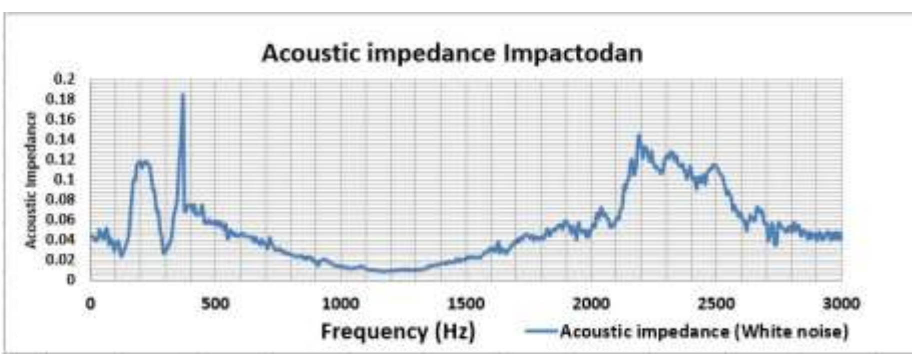

Fig. 8. *Acoustic Impedance for Impactodan sample utilizing white noise with 5 Hz resolution*

The sound impedance of the Impactodan sample, depicted in "Fig. 8." above, also presents a pattern opposite in direction to the absorption coefficient but with a lot of variations, showing that this sample has a high resistance to sound. Due to the sample's reduced thickness in comparison to other samples which has significantly bigger thickness sizes, it would not be able to transfer the majority of sound energy directed to it.

5. CONCLUSION

Evaluation of white noise's acoustic performance with some industrial insulation materials was presented. It was noted that the method generates a larger range of outputs that are compatible with the expected outcomes because it considerably increases the resolution of frequency (instead of applying a set octave frequency ranges as previously done). The results of this research show that some materials, except the Impactodan sample that was examined, do function effectively as insulation material when used alone, due to the properties of high impedance. The materials' porous composition and density also played a significant role, it was also discovered that the higher the absorption coefficient, the lower the acoustic impedance [4]. This is to say the materials in this study with the exception of Impactodan can reflect and absorb a majority of the sound energy channeled toward them. Impactodan sample can also perform better if its thickness is increased to almost six times its present thickness. It can be concluded that the use of white noise in this measuring approach to evaluate the acoustic absorption coefficient and sound impedance yields a wide range of data, facilitates measurement, and enables the efficient performance presentation of the evaluated samples.

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