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Acoustic Absorption Coefficient of Polyethylene using Two-microphone Transfer Function Method

James C. Espinosa, Claude R. Ceniza, and Renante R. Violanda

***Abstract*—Noise Pollution has been a prevailing issue in our classrooms that affects the physiological processes and psychological health of our students in public schools specifically. The study aimed to measure the absorption coefficient of waste polyethylene foam, used as dumping material for our laboratory equipment, to determine if we can possibly reuse it as an acoustic material to make our classrooms more conducive to learning. Its absorption coefficient was measured using two-microphone transfer function method. A sample of the foam was inserted into the impedance tube and was exposed in a stimulus to quantify the complex transfer function. The results were used in the calculations for the reflection and absorption coefficient of the material. Uniform and Gaussian white noise were used as excitation signals to test its acoustic properties. Furthermore, the study also investigated the effect of the thickness, (1.0 in. to 2.0 in.), to its efficiency in absorbing sound energy. The results showed that thickness affects the efficiency of the material in absorbing sound energy and the 1-inched thick sample is the most absorbent amongst the thicknesses. Thus, the installation of this type of polymeric foam in our classrooms could possibly help in eradicating the noise pollution experienced by the students and teachers inside the classroom.**

***Index Terms*— Absorption Coefficient, Impedance tube, Transfer function Method, Reflection Coefficient.**

I. INTRODUCTION

Noise pollution is one of the serious issues of the present society because it affects human physiological processes and psychological health. Unfortunately, this problem is evident in our public school classrooms where it is supposed to be conducive for learning.

Our students spend large amount of time in their classrooms to listen their teachers' discussions to acquire knowledge and to learn essential skills for the benefit of their future.

Research shows that chronic internal classroom noise exposure of young children has detrimental effect on their learning and attainment. Children are deficit in sustained attention and visual attention; poorer auditory discrimination and speech perception; poorer memory for tasks that require high processing demands of semantic material; and poorer reading ability and school performance on national standardized tests [8].

Ideally, classrooms should have reverberation times in the range of 0.4 - 0.6 seconds, but most of our classrooms exceed this limit [11]. For this reason, our classrooms became unconducive for learning.

To address this problem, installation of porous material such as glass wool, wood panels, dimensional fabrics and polymeric foams as acoustic material is highly recommended to minimize the reverberation time of the sound waves as it reflects on the concrete walls.

A porous acoustic material is a solid that contains cavities, channels or interstices so that sound waves are able to enter through them [1]. It softens the acoustic environment of a closed volume by reducing the amplitude of the reflected waves and reducing the energy of the sound wave by converting the mechanical motion of the air particles into low-grade heat. There are two classifications of this material based on their microscopic configurations: fibrous or cellular. Fibrous materials consist of a series of tunnel-like openings, formed by interstices in material fibers, such as glass wool and wood panels [1]. Cellular materials consist of open and closed-celled polymers such as polymeric foams.

Between these two classifications of porous materials, cellular-classified material is extensively used as acoustic material because of its excellent performance in attenuating vibrations and absorbing sound energy [8]. It decreases the sound and the mechanical vibrational energy of the acoustic waves by converting the energy into low-grade heat as it propagates in the foam. This is due to air friction inside the polymeric cells and viscous friction between adjacent polymer chains [8].

Polyethylene foam, a type of polymeric foam, is used as a wrap for fragile goods due to its excellent vibration dampening property. Most of the waste of this polymeric foam ends in our landfill that also adds to our problem with non-biodegradable materials in our country.

This has led the researcher to determine if we can reused this viscoelastic polymeric foam as an acoustic material to address the noise pollution in our classroom and our environmental problems with non-biodegradable waste .

Research shows that a number of conditions, including age and physical conditions can affect human sensitivity to a particular frequency. The most important frequencies for understanding speech are typically in the range 500 to 2050 Hz.

Materials and structures that can absorb frequencies in this range are important tools in managing the acoustic environment for the health, safety, and comfort of people exposed to noisy environments. Furthermore, this material of different thickness is exposed to two different stimuli, Gaussian White Noise and Uniform White Noise, to simulate the real life noise.

II. METHOD

A. Two microphone – Transfer Function Method

The measurement and the processing of data were done in the program created in the LabVIEW™ from which the transfer functions of the signals were evaluated. This program is used for the measurement of the signals detected by the two microphones and computes the transfer function as

$$\frac{\text{Cross spectrum of mic 1 to mic 2}}{\text{Auto spectrum of the mic 1}}$$

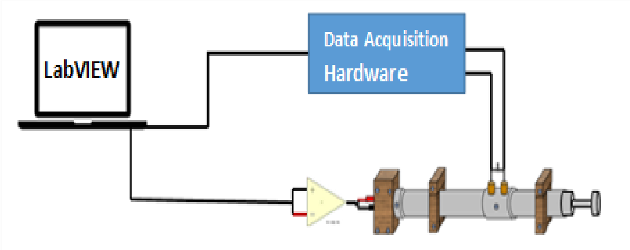


Fig. 1. Schematic diagram of the experimental setup.

The amplifier is connected to the speaker of the impedance tube and to the PC with LabVIEW™ program where the excitation signal is generated.

The microphones mounted in the tube are connected to the data acquisition hardware in which it is connected to the PC. To guarantee the optimum sound pressure that the microphones can measure, microphone 2 is located one lateral diameter from the rigid end of the impedance tube where the sample is mounted and microphone 1 is located 80mm away from microphone 2.

The LabVIEW™ generates white noise in the tube, and the decomposition of the interference field is achieved by the measurement of acoustic pressures at two fixed locations and subsequent calculation of the complex acoustic transfer function of the acoustic material.

B. Optimization of Experimental Setup Results

To guarantee that the setup will yield an optimum result, the location of the microphones and the selection of the thicknesses of the sample where followed.

Microphone 2 is mounted one lateral diameter from the rigid end of the impedance tube where the sample is mounted to ensure that all the measure reflecting waves, propagating from the sample, sound pressure are only plane waves. On the other hand, microphone 1 is mounted 80mm away from microphone 2 to ensure that the location of the microphone is in a point of high mode [4].

For the sample to significantly absorb sound energy, the least thickness is higher than a tenth of the wavelength and the thickest is about a quarter of the wavelength of the lowest frequency [4].

C. Experimentation Procedure

The polyethylene foam, mounted at the end of the impedance tube on the surface of the rigid termination. After securing the sample at the end, a sound source, is generatedfrom the PC through the speaker connected at the other end of the tube. The transfer function of the two microphones (H_{12}) will be measured and analyze by the FFT (Fast Fourier Transform) analyzer. The computer program that was created in the LabVIEW™ automatically gives the average H_{12} of the 300 trials conducted.

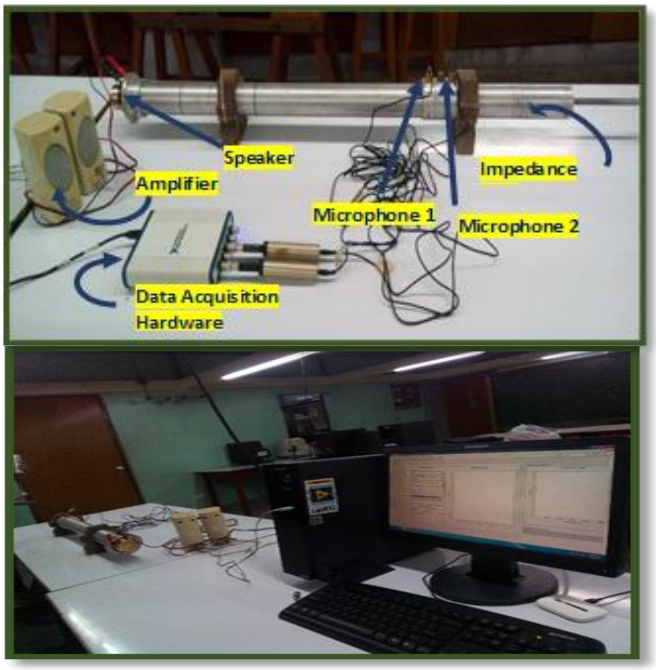


Fig. 2. Actual experimental setup.

D. Calculation for the Reflection Coefficient

The obtained H_{12} values are used to calculate for the reflection coefficient of the material using

$$R = \frac{H_{12} - H_I}{H_R - H_{12}} e^{jk2l} \quad (1)$$

where l is the distance from mic 2 to the surface of the sample [4].

E. Correction for Microphone Mismatch and Amplitude Gain

When using the two-microphone technique, the phase mismatch between the microphones is unavoidable and must be corrected. To correct this error the researcher adapted calibration factor method [2]. The H_{12} of eq. 1 is obtained from

$$H_{12} = \frac{H_{12}^{I}}{H_c} \quad (2)$$

where H^{I}_{12} is the original configuration of the microphone along the tube and H_c is the calibration factor obtained from

$$H_c = \sqrt{\frac{H_{12}^{I}}{H_{12}^{II}}} \quad (3)$$

and H^{II}_{12} is the switched configurations of the microphones.

F. Correction for Tube Attenuation

The incident and reflected sound waves that propagate within the tube are subject to attenuation due to viscous and thermal losses. To correct for tube attenuation, the researcher adapted with the standard technique [2]. It is to replace the real wave number k by a complex wave number:

$$k' = k - k'' \qquad (4)$$

where k= 2πf/cn and k" is the attenuation constant, based on the standard, attenuation constant has an empirical relationship of

$$k'' = A\frac{\sqrt{f}}{cd} \qquad (5)$$

where A = 0.02203 [2], c is the speed of sound, f is the frequency, and d is the diameter of the tube.

Thus, the final equation used for obtaining the reflection coefficient of the test material was

$$R = \frac{H_{12} - H_I}{H_R - H_{12}}\, e^{jk'l} \qquad (6)$$

G. Calculation for Absorption Coefficient

Since the impedance tube is assumed as an acoustically closed system, this must imply that the part of the incident-propagating wave that is not reflected by the material must be absorbed, therefore can be derived with the use of Eq.7 as

$$\alpha = 1 - |R|^2 \qquad (7)$$

H. Savitzky – Golay Filter

In measuring acoustic reflection capacity of a material using an impedance tube noise in the results is inevitable. This causes glitches and spikes of the plot that may lead to an erroneous conclusion. To eliminate this error, the researcher applied this low-pass filter to smoothen noisy data of the reflection coefficient that is further used to obtain the absorption coefficient of the material. The data is substituted to equation 5.

$$y_i = \frac{1}{5175}\left[\sum_{n=12}^{-12} c_n f_{i+n}\right] \qquad (5)$$

where y_i is the filtered data, fi is the data to be filtered, c_n is the coefficients of the polynomial fit and n is the number of points used "to the left and to the right" of a data point.

III. Results

The obtained reflection and absorption coefficient results of the materials are outlined systematically in this chapter. Two independent tests were conducted using two different excitation signals in the impedance tube, Gaussian White Noise (GWN) and Uniform White Noise (UWN).

A. Reflection Coefficient

(a)

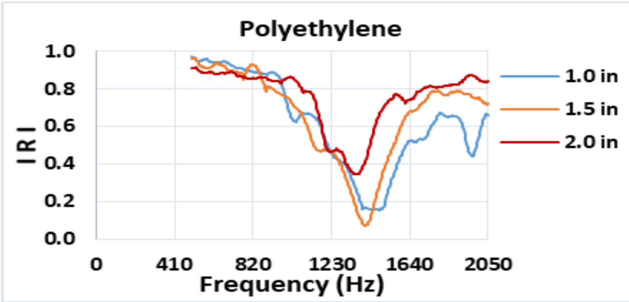
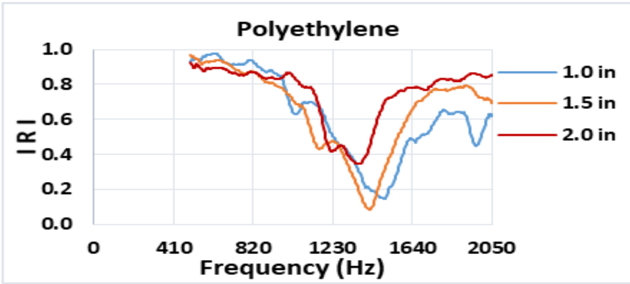


Fig. 3. Magnitude of the reflection coefficient of three of different thickness using Gaussian white noise.

(b)

Fig. 4. Magnitude of reflection coefficient of three of different thickness using uniform white noise.



From the plots of figure 3 and 4, it is evident that the reflection coefficient results are consistent in the experiment employed with two different excitation signals.

Furthermore, the test material has lesser value of reflection coefficient |R| in the thickness of 1.0 in and 1.5 in which tell us that it reflects less sound energy in this thickness.

Nevertheless, the polyethylene reflects more energy in frequencies with wider wavelength and polystyrene reflects less energy in frequencies with narrow wavelength.

This is caused by the porosity of the test material. Materials that have bigger pores like polyethylene are effective in reflecting less energy of the frequencies having a wide wavelength.

As reflected in the plot, all the thickness of the test material significantly reduced the reflected sound energy in both excitation signals employed in the experiment.

B. Absorption Coefficient

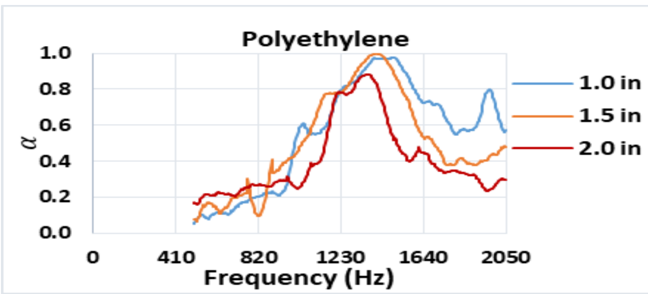


Fig. 5. The Absorption coefficients of the polymeric foam of three different thicknesses.

From the plot in figure 5, 1.0-inch thick of polyethylene foam has higher results of α which implies that this thickness is efficient in converting the energy of the impinging wave into low-grade heat. Thus, it reflects less energy carried by the reflective wave and absorbs much of the energy of the impinging wave.

IV. Conclusion and Recommendations

From the results shown and discussed in Chapter III, we can conclude that polyethylene is efficient in absorbing sound energy of the chosen frequency range and works best if it has a thickness of 1.0 in. and 1.5 inches.

Therefore, the installation of this type of plastic waste could possibly help in making our public classrooms more conducive to learning and we can reduce our waste by reusing this material for another purpose.

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