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ORIGINAL ARTICLE

Determining and Comparison of Sound Absorption Coefficients using Small Reverberation Chamber and Test Tube Methods

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ABSTRACT

Sound absorbing materials have been widely used to decrease hazardous noise in indoor and outdoor environments. In the present study, we designed and constructed an experimental laboratory-scale chamber to measure the sound absorption coefficients of porous materials in comparison with the measurements of the test tube method. The main reason was to design and construct a small chamber to enable testing of acoustic material samples in small dimensions allowing easy and rapid testing of acoustic materials. The acoustic chamber method was based on the formation of reverberation field of the acoustic waves across testing chamber locations, but differences in sound pressure throughout the chamber may result in measurement errors. Therefore, the chamber was constructed with a volume of 2.85 m3, wall reflectors, and a rotating sound source was designed to ensure a diffusive field. The tests were conducted with samples of 12.4m2 installed on interior surfaces of the chamber. Sound absorption coefficients of acoustic polyethylene and polyurethane absorbents were measured across the central frequencies of the octave band. Sound absorption coefficients under reverberant random incidence and normal incidence were related to the sound frequency. The chamber method predicted higher sound absorption coefficients compared to the coefficients obtained by the tube test method for all tested porous materials. Based on the results of the proposed small chamber, it can be concluded that sound absorption coefficients measurement of samples in an environment was more similar to real situations.

KEYWORDS: *Noise, Acoustics, Materials Testing, Absorbent, Sound Absorption, Diffusive Chamber*

INTRODUCTION

Noise is widely recognized as a hazardous environmental and occupational factor for various harmful effects on human well-being and safety, less work performance, and productivity [1-2]. Previous noise exposure assessments suggest measuring,evaluating, and control of sound pressure and intensity levels throughout the sound frequency spectrum.[3-2] .

Previous studies on noise assessment in various industrial environments have shown that noise is typically generated in frequencies ranging between 30 to 8,000 Hz, depending on the type of sound sources. However, occupational exposures to noise are more common in medium and high-frequency ranges rather than low-frequency ranges [3-4]. The results of studies showed that exposure to high sound levels in higher frequencies might increase the risk of occupational hearing loss compared to sound levels in lower frequencies [5]. Acoustic absorbers are widely being used effectively to reduce and control noise propagation in working settings [6-8].

In previous studies, researchers have sought to make adsorbents with simple manufacturing processes and low costs to reduce noise [8-9]. The sound absorption property of acoustic materials was expressed by the sound absorption coefficient α, which was a function of the sound frequency. For acoustic evaluations, the average absorption and reduction of acoustic waves at the central octave frequencies of 250, 500, 1000, and 2000 Hz were calculated [10]. The value of α varies from zero to one, indicating complete reflection and absorption, respectively [11-13].

The sound absorption coefficient for absorbents was commonly determined by impedance tube and reverberation chamber testing methods [10-14-15]. The experiments in the impedance tube method were based on the formation of the standing wave. Previous studies reported small-size samples and shorter periods of test requirements as the most important advantages of the impedance tube method. However, the tube approach of testing sound absorption properties of materials was far from real working conditions [10].

The propagation of diffused or diffuse sound waves is the most important action mechanism feature for estimating the sound absorption coefficient in the reverberation chamber. The reverberation method assumes the incidence of sound waves in random and uniform energy levels inside the chamber treated with sample [16]. By comparing the decay rate of the untreated and treated room with the sample, the statistical absorption coefficients of the absorbing material were measured at the preferred octave band center frequencies. According to Derabak's laboratory experience, in order to propose a new material as a sound absorbent, the impedance tube method provided a better method for determining the characteristics of the small samples in sound absorption [15]. However, laboratory experiences have shown that the reverberation method performed in a room space can more accurately measure the acoustic absorption of the material. Hence, the measurement of acoustic coefficients using the reverberation room requires more time and a larger sample than the impedance tube method. There is generally no consensus on the use of the impedance tube method in practical conditions to determine the absorption of sound-absorbent material. The reverberation approach could provide a more representative testing situation of the real application of absorbents in determining the absorption coefficient of acoustic samples [9].

Currently, acoustic absorbing materials are being developed to reduce hazardous noise in work environments. In recent years, there has also been a growing interest in the development of laboratory methods for measuring sound absorption. Although past experiments revealed that reverberation chamber was a suitable method for determining the absorption coefficient of absorbing materials but the testing method had limitations in terms of designing dimensions and geometrical shape and amount of required sample. Acoustic chambers were designed in small and large-sized dimensions to generate a perfect reflection field. Designing the appropriate method for creating a complete reflectance field and suitable laboratory dimensions that be able to easily and accurately measure the acoustic absorption of various adsorbents in a short time was one of the major challenges [11].

The purpose of this experimental study was to design and construct a complete small-sized reverberation chamber to determine the absorption coefficients of different acoustic absorbers. In this study, the sound absorption coefficients of polyethylene and polyurethane were investigated using the reverberation chamber and impedance tube methods. Designing a sound diffused chamber with a small volume would take less space and require a small sample size and thus reducing cost and time for the absorbent material test.

Method of chamber design and construction:

The main criterion in this experimental study was the design of the chamber based on the formation of the reflection field of the acoustic waves in the interior of the chamber. Therefore, prior experiments were chosen as a guideline in devising the appropriate dimensions of the chamber to ensure diffusive sound propagation [17]. We proposed asymmetrical dimensions to avoid standing waves and to enhance sound level uniformity throughout the chamber space.

The set requirements in the standard method for the formation of the reflection chamber of As1045 were also considered in the design and construction of the chamber. In the design of the chamber, the maximum longitudinal dimensions of the chamber were calculated in terms of its volume and using the equation of $L_{max} \leq 1.9\ V^{(1/3)}$, where chamber volume was 2.85 m3 and the calculated maximum length was 2.7 m but the created maximum length of the chamber was 1.8 m. The smallest longitudinal dimensions of the chamber in meters were calculated on the basis of a 200 Hz wavelength using the equation of $L_{min} > 1/2\ \lambda_{200}$ that a calculated minimum length was 0.85 m but a created minimum length of the chamber was 0.91 m. Details of the design of the chamber have been shown in Figure 1.

The aim of this project was the design and construction of a chamber to determine the absorption coefficients of acoustic materials performed in the physical factors laboratory at the Medical Sciences University of Semnan according to the mentioned standards. A Styrofoam with 30 mm thickness was used to reduce the cost and lightness of the surfaces and the ability to disassemble the chamber components. The surfaces of the chamber were covered by aluminum foil with 0.2 mm thickness using wood cement to make a maximum reflection inside the chamber. According to the experiences obtained from the previous studies and standards mentioned in the design, its area and volume were 12.4 m2 and 2.85m3, respectively.

The chamber was placed in the corner of a room so that three sides of the floor and its two walls were fixed on the walls of the room so that the chamber would be strong and vibration resistant. The smallest wall had a sliding design that provided access to the chamber.

A DC motor with adjustable rotation speed was installed in the center of the roof of the chamber to emit sound waves uniformly in all directions as a point source. A rechargeable cube sound source was used to play the sound. As shown in Figure 2 during test performance, the sound source was hanged to the motor by a thread so that the sound source was placed in the center of chamber volume and the sound source rotation rate was set at 120 rpm to emit sound in all directions inside the chamber.

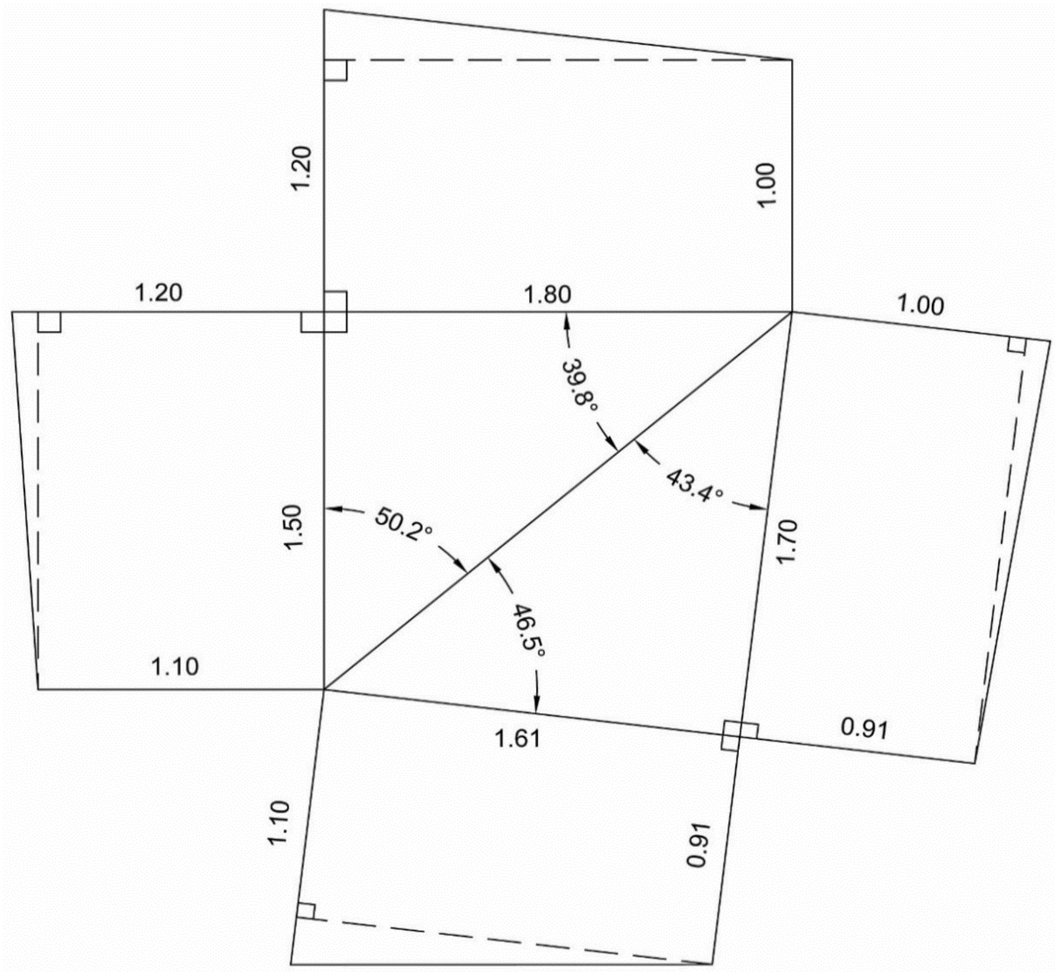

Fig 1. Design dimensions of sound diffusive chamber (The values were in meter)

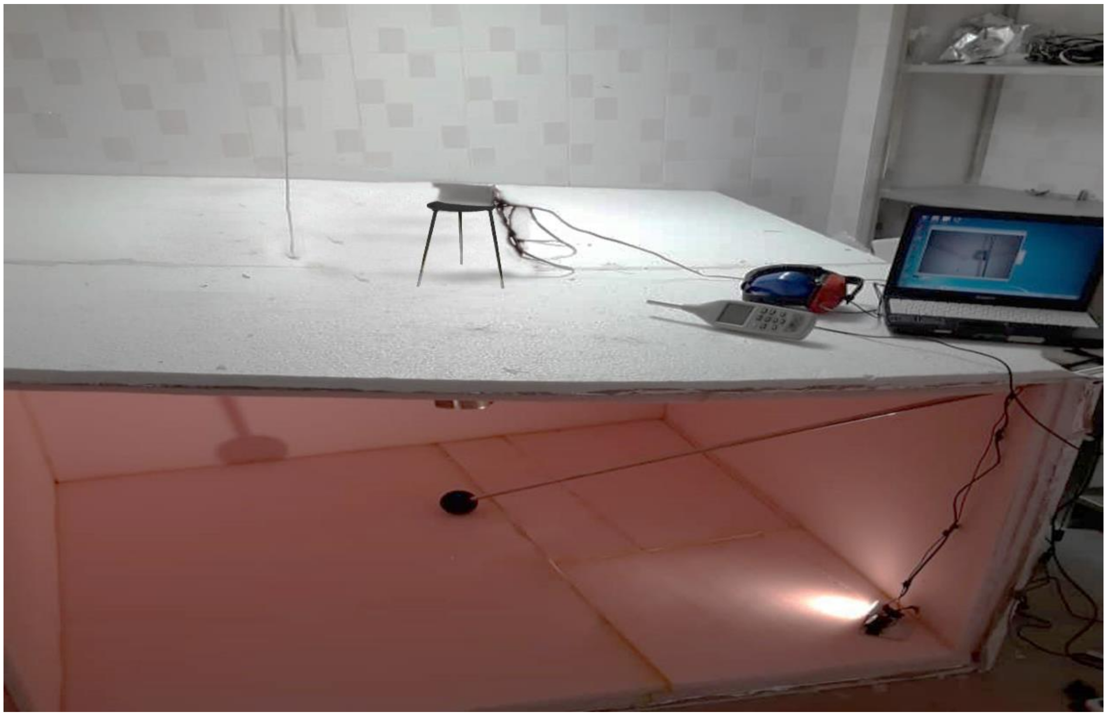

Fig 2. Reverberation chamber experimental setup

The audio source generates sound pressures of 81, 92, 95, 96, and 96 dB at the octave central frequencies of 250, 500, 1000, 2000, and 4000 Hz, respectively. As shown in Figure 2, the microphone was connected to the end of a steel tube with a length of 2.8 m and the tube was inserted from one corner of the chamber to measure the pressure level of sound at the desired points. A webcam was used to record the position of the microphone inside the chamber and a halogen LED lamp was used to illuminate the chamber. The gauge level of sound was calibrated by TES 1356 calibrator at the frequency of 1000 Hz and 94 dB pressure level. Using the gauge level of sound with the TES 52 model can be directly measured the minimum and maximum pressure amplitude values.

The constructed chamber was then carefully treated with the acoustic insulation specimens to perform the measurement. The samples applied for estimating their relevant absorption coefficients consisted of open-cell polyurethane foam with a density of 18.65 kg / m3, and thickness of 25 and 50 mm, and polyethylene foam with a density of 22.2 kg / m3, and thickness of 9 mm.

Before placing the absorbent sample in the acoustic chamber, the pure sound pressure level was measured at 8 points according to Figure 3, at four points in the middle of the chamber faces and four points in the corners of the chamber. The sound pressure levels were measured the same throughout the chamber at the specified octave-band center frequencies, representing a diffusive and uniform field inside the chamber.

Then, all the interior surfaces of the chamber were treated with sound-absorbent materials. The reflected sound pressure levels from the absorbent sample were measured at the specified points as shown in Figure 3. The sound absorption coefficients of the same sound-absorbent samples were determined by the impedance test tube at the physical factors laboratory of Hamadan School of Health.

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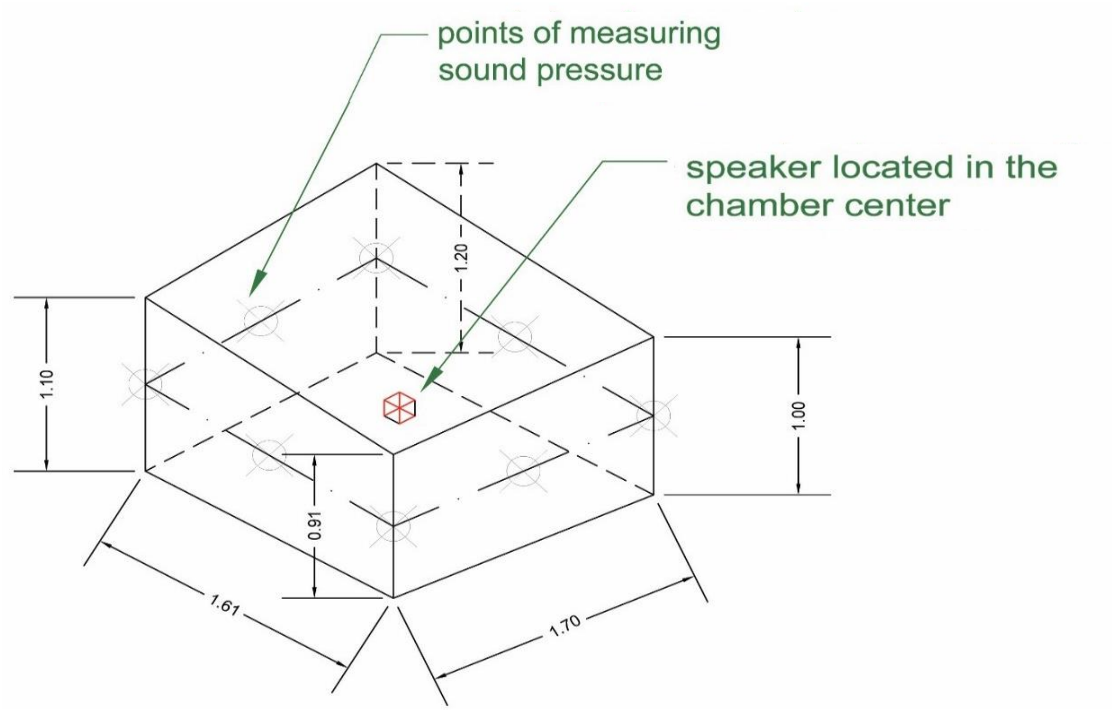


Fig 3. Chamber isometric projection and points of measuring sound pressure (The values were in meter.

To measure the absorption coefficient (α) of the adsorbent at a given frequency, the ratio of absorbed acoustic energy (E_{abs}) to sample input energy (E_{ins}) was calculated using Equation 1 [11-12-18].

$$\alpha = \frac{E_{abs}}{E_{ins}} \quad (1)$$

To determine the average absorption coefficient (α_a) of each adsorbent, the average sound absorption coefficients obtained at the central frequencies of 250, 500, 1000, and 2000 Hz were calculated using Equation 2.

$$\alpha_a = \frac{\alpha_{250}+\alpha_{500}+\alpha_{1000}+\alpha_{2000}}{4} \quad (2)$$

RESULTS

Diffusive field test:

The sound pressure levels emitted at various points of the chamber space were measured at different octave-band central frequencies to determine the formation of a reflection field in the chamber. Table 1 shows the results for source acoustic power and sound pressure levels in different points of the chamber.

Table 1. Sound pressure levels measured inside the chamber

Frequency bands (Hz)	Source sound pressure levels (dB)	Chamber sound pressure levels (dB) Mean ± SD
250	81	81±1
500	92	92±1
1000	95	95±1
2000	96	96±1
4000	96	96±1

The sound level meter measured uniform sound pressure levels at each central frequency of the octave band, indicating a uniform and random sound reflection field throughout the test chamber.

Figure 4 shows the sound absorption average of the materials tested using the reverberation chamber method and the impedance tube method. The results indicated that with increasing thickness of polyurethane foam, the changes of absorption coefficients in the impedance tube method were more than that of the reverberation chamber method and the sound absorption average of polyethylene foam in the impedance tube method were significantly lower than in the reverberation chamber method.

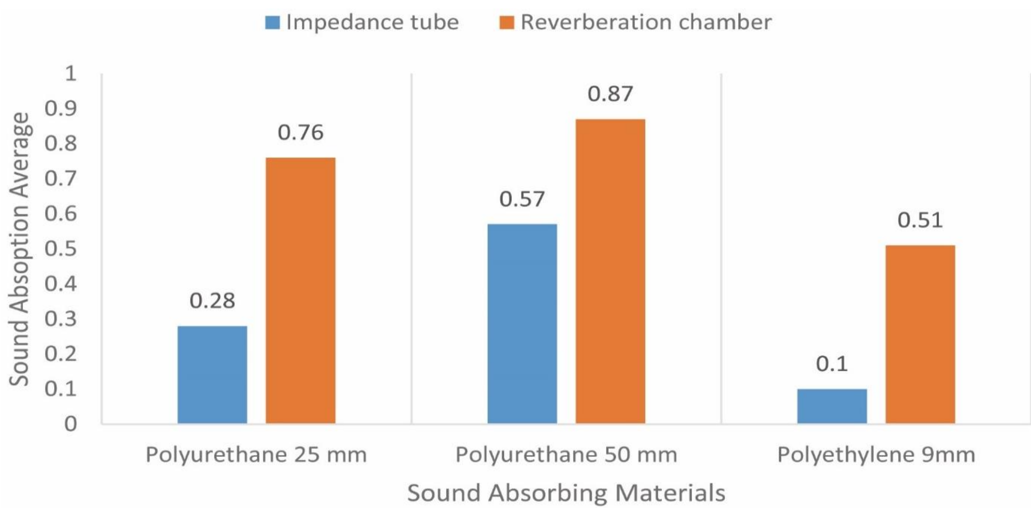
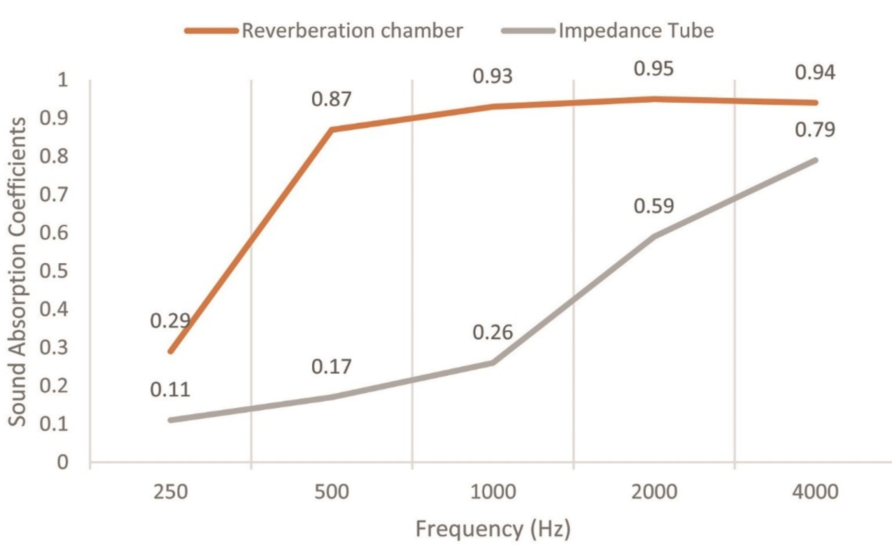


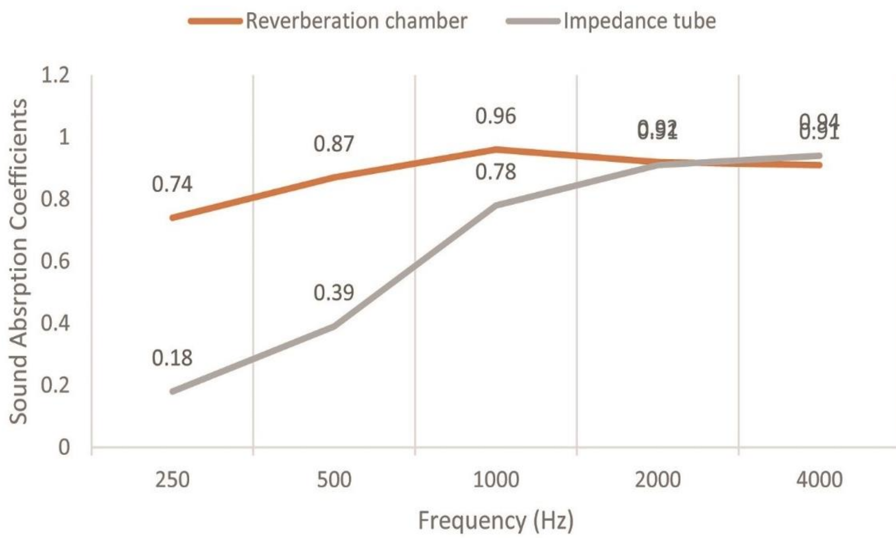
Fig 4. Sound absorption average coefficients of acoustic materials using the impedance test tube and reverberation test chamber

Acoustic absorption coefficient measurements:

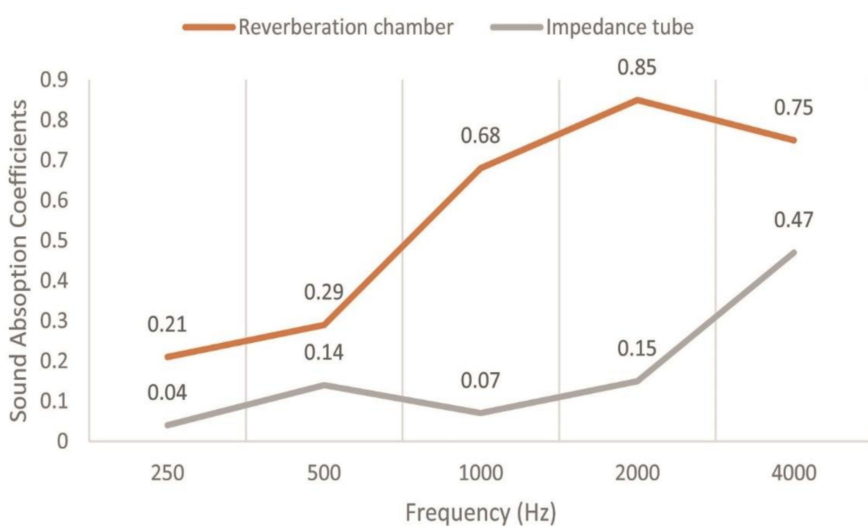
Figure 5 shows the sound absorption coefficients of acoustic materials in the reverberation chamber and the impedance tube in the octave central frequencies, respectively. Based on the results of the two testing methods comparison, it was found that the absorption coefficients in the reverberation chamber method at frequencies below 1000 Hz were much higher than the absorption coefficient in the impedance tube method. In addition, the results of the absorption coefficients in the reverberation chamber showed that the absorption coefficients were at high levels at central frequencies of 1000 and 2000 Hz, while absorption coefficients in the impedance tube method increased at higher frequencies. Adsorption measurement of polyurethane in the chamber and impedance tube revealed that doubling the thickness of the absorbent may lead to the same sound absorption coefficients at frequencies 2000 and 4000 Hz.



(a)



(b)



(c)

Fig 5. Sound absorption coefficients of tested materials by reverberation chambers and impedance tube. a: polyurethane 25 mm; b: polyurethane 50 mm; c: Polyurethane with thickness 9 mm.

DISCUSSION

The purpose of this study was to design and construct a reverberation chamber for measuring the sound absorption of acoustic absorbers and to compare the acoustic absorption coefficients measured using the reverberation chamber method with the acoustic impedance tube method.

In the present study, the results of sound measurements in the chamber showed that the created sound field had favorable reflectance conditions at different octave-band frequencies in terms of sound pressure level. This experiment revealed that the spatial volume of 2.85 m3 provided a chamber with the required reverberation field. Moreover, while the diffusive field criterion suggested a maximum chamber length of 2.7 m, our chamber was 1.80 m in length.

Prior experimental tests showed that a reflection field without changing the diffusion in the chamber can create by balancing the dimensions of the chamber, its volume, and chambers with the volume of 238 m3 were used for standard reflectance chamber and the volume of 1.12 m3 was used to create the Reverberation condition for a small chamber. In the chamber designed by Hernandez et al., the chamber volume was calibrated to achieve a reverberation room of 3 m3 and to test the sample with an area of 0.4 to 1.4 m2 [19]. In the present study, the dimensions of the chamber were adjusted to test the sample with an area of 12.4 m2. Researchers used different volumes to design reverberation chambers in experimental studies but the maximum permissible length of the chamber was considered in all cases [20].

The results of absorption coefficients obtained in the small-sized chambers were similar to room-sized chambers in other research experiments [21]. Furthermore, the small dimensions of the chamber will allow the use of a small piece of testing sample for determining sound absorption properties of acoustic materials [20] Uncertainty analysis of standardized measurements of random-incidence absorption and scattering coefficients.

Overall, our experiments showed that the acoustic chamber and test tube yielded variations in the measurement of sound absorption coefficients. The absorption coefficients of polyethylene obtained by both the reverberation and impedance tubes were lower than the figures for polyurethane. The difference of absorption coefficients in tested materials can be attributed to the open porosity of polyurethane facilitating sound waves penetration in the material texture but polyethylene was formed by closed porosity allowing sound wave emission.

One of the most important results of the present study was that the absorption coefficients of the reverberation chamber method were often higher than the impedance tube method. The obtained results were in agreement with the results of the Drabek study [15]. According to the present study, it seems that the absorption coefficients of low-frequency sound in the reverberation chamber method were higher than those obtained in the impedance tube method. The previous experiment suggested that at low frequencies impedance tube measurements result in imprecise absorption coefficients, which may be attributed to sampling attachment inside the tube [5].

The two methods showed slight differences in the measurement of absorption coefficients for thicker absorbents. Increasing the thickness of polyurethane at the frequency of 250Hz in the reverberation chamber method had a significant effect on the sound absorption coefficient and at high frequencies had no significant effect on the sound absorption coefficient, which was consistent with the research of Khorasani and Koohnavard [3-18]. However, the sound absorption coefficient in the impedance tube method increases with increasing absorbent thickness. Absorption coefficients determined by impedance tube for tested materials were similar to the measurements reported in the previous experiment by Aliabadi et al [10].

Calculation of absorption coefficient by reverberation chamber method yielded more reliable and applicable than the impedance test tube [10-14-15]. However, the room method test requires a large space and a large amount of absorbent material, which limited its application. This method was also costly and takes much time [10]. In this study, a small reverberation chamber was designed to be reliable the absorption coefficient calculated by it and also save time and cost. Practically, the measurement of absorption coefficients differs from theoretically predicted random incidence absorption because of lacking a random incidence absorption coefficient. The chamber reverberation room with random sound propagation and incident on the absorbing sample predicted higher values of absorption coefficients compared to the tube method with a normal incident of sound waves. Small chamber dimensions may improve the measurement of sound absorption coefficients [21-22].

The results of the reverberation chamber experiment showed that the polyurethane acoustic absorption coefficient was higher than polyethylene because it had a porous and flexible surface and reduces vibration and sound energy. Therefore, it had a good performance in the absorption of sound waves. However, the non-porous surface of polyethylene was flexible and reflected the sound waves into the environment. Our results were consistent with Wang's study that reported polyethylene possesses sound absorption property at higher frequencies while polyurethane provides sound absorption over a wide range of frequencies [23]. Moreover, Polyurethane converts vibration and sound energy into heat energy. Polyurethane acoustic performance may be enhanced in a variety of ways, typically changes in solid phase chemical structure and adding the additives [24-25].

In our study, the experiments performed by impedance tube and reverberation chamber for determining the absorption coefficients of the same samples resulted in different measurements. Similarly, McGrory et al., reported different estimations of absorption coefficients following experiments with two methods [12].

CONCLUSION

The present experimental study was focused on the design and fabrication of a small-scale reverberation chamber to determine the absorption coefficient of acoustic materials to compare the efficiency of acoustic material tests with acoustic impedance. One of the most important results of using the small-scale reverberation chamber was saving the cost and reduction of the necessary time for the determination of the noise reduction capability of acoustic materials at different frequencies.

One important conclusion that can be drawn from the present study was that the data obtained from the acoustic absorption coefficients in the two methods of the reverberation chamber and the impedance tube were not identical and researchers need to pay special attention to this issue at the estimation of the material acoustic absorption coefficients. The uniform sound pressure levels measured at different positions in chamber space provided good criteria and validity for determining sound absorption coefficients of acoustic materials [26]. Our experiment of the small-scale diffusive chamber revealed similar measurements of sound absorption coefficients for the same samples when compared to the room-sized diffusive method [21]. Moreover, in comparison with the impedance test tube method, the diffusive chamber permits acoustic absorption tests under more real working conditions where sound-absorbing samples were used [15]. Therefore, a small-sized reverberation chamber could provide a more reliable measurement of statistical sound absorption of acoustic materials across low and high frequencies. Additionally, the chamber method experiments showed that noise reduction level was linked to acoustic absorbent features such as porosity, thickness, and airflow resistance. This study emphasized that the small-scale reverberation chamber would be used to measure the absorption coefficients of different acoustic materials for practical applications.

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CONFLICT OF INTEREST

The authors had no competing interest in this study.

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