

original article

Assessment of normal incidence absorption performance of sound absorbing materials

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ABSTRACT

Aims: The purpose of the present work was to consider the effect of different samples thicknesses on the acoustic absorption coefficient.

Materials and Methods: An impedance tube was built with two microphones accordance to ISO-10534 and the American Society for Testing Materials-E1050 standards. For the measurement of absorption, the study was carried for 25 and 30 mm thicknesses of closed cell polyurethane foam, polystyrene, polyvinyl chloride (PVC), rubber, mineral wool, carpet, and glass samples. Measurements were performed by impedance tube and VA-lab4 software.

Results: In carpet and mineral wool with more thickness, the absorption was increased but, the carpet with less thickness showed more sound absorption in the frequency range of 1500–3600 Hz. The peak of the absorption coefficient of 25 mm glass was 0.36 that the amount was reduced to 0.2 in the 30 mm thickness. Furthermore, the difference between the peak absorption of two thicknesses in polystyrene sample was equal to 0.29. In fact, polystyrene with less thickness had better sound absorption. The same situation was happened for glass in frequencies of below 4500 Hz with less thickness.

Conclusion: Incident sound energy, which is not absorbed, must be reflected, transmitted, or dissipated. The porous materials had a higher absorption coefficient. Carpet and mineral wool samples had the highest absorption coefficient, but the materials such as polyurethane foam, PVC, and rubber had lower sound absorption.

Key words: Impedance tube, reflection coefficient, sound absorption coefficient, sound absorbing material, transfer function

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INTRODUCTION

It is actually undeniable that the development of global industry, science and technology has significantly improved the quality of life. However, this process also simultaneously leads to numerous problems, especially environmental issues and human's health. Every day, billions of people throughout the world have to exposure with several uncomfortable effects such as: air pollution, water pollution, and so forth. Besides these, noise pollution can also be seriously influencing human's life as well,

especially the lives of city's dwellers. Noise pollution is produced from many different sources. This can be the results of industrial functions or from the everyday life's actions. Since the noise problem has become much more complex and serious, the needs for a better environment and more diversified life-styles increased. Thus, the materials that can absorb sound waves in wider frequency regions are strongly desired.^[1,2]

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Materials that reduce the acoustic energy of a sound wave as the wave moves through it by the phenomenon of absorption are named sound absorptive materials. They are typically used to soften the acoustic environment of a closed volume by reducing the amplitude of the reflected waves.^[3] Sound absorptive materials are usually used to counteract the undesirable effects of sound reflection by hard, rigid, and interior surfaces, and therefore, help to reduce the reverberant noise levels.^[3,4] The important uses of acoustical materials are almost invariably discovered include the reduction of reverberant sound pressure level and consequently the reduction of reverberation times in enclosures.^[5] There are two standardized methods for measuring the normal sound absorption coefficient: one using standing wave ratio standardized in ISO-10534-1 and transfer function method standardized in ISO-10534-2.^[6,7]

Impedance tube provides a convenient laboratory method of measuring the acoustic absorption coefficient of small samples for sound waves normally incident on their surfaces. The sample material is mounted one of a rigid and straight impedance tube and loudspeaker is mounted in the tube at the other end.^[7]

In one research, Utsun *et al.* measured the acoustic features of glass fiber and aluminum by the transfer function method and compared with the actual values.^[8] Koizumi *et al.* showed the increase of sound absorption value in the middle and higher frequency while the density of test sample increased. The number of fibers raises per unit area when the apparent density is large. Energy loss raises as the surface friction raises thus the sound absorption coefficient increases.^[9] Shoshani and Yakubov reported that, in designing a nonwoven web to have a high sound absorption coefficient, porosity should increase along the propagation of the sound wave.^[10] Simon and Pfrezschner combined absorptive materials with barriers produce composite products that can be utilized to lag pipe or provide absorptive curtain assemblies.^[11] In another study, Jayamani and Hamdan measured the sound absorption coefficient of two kinds of polymers (urea-formaldehyde and polypropylene) mixed with natural fiber (kenaf) according to the American Society for Testing Materials (ASTM E1050-10) and transfer function method.^[12]

Unfortunately, there are no specific sound absorption coefficients for the Iranian absorbent materials. Therefore, motivated by the investigations mentioned above and the importance of acoustic characteristics of sound absorbing materials, the purpose of the present work was to measure the absorption coefficient of seven samples by impedance tube with two microphones and transfer function method. Furthermore, the effect of thickness was considered on the sound absorption coefficient of studied materials.

MATERIALS AND METHODS

The impedance tube with two microphones, seven different samples, loudspeaker, frequency analysis system from BSWA Technology Company, personal computer with

VA-lab4 software from BSWA technology, and calibrator were prepared for this experiment. For this purpose, first was built the impedance tubes with the following features.

Impedance tube specifications

The sound absorption coefficient of material is determined by impedance tube in according to ISO-10534 and ASTM E1050 standards and based on transfer function method. This paper was focused on the ISO-10534 standard. The impedance tube with smooth and nonporous wall without holes (except at intended microphone positions), strong and thick wall enough to prevent of vibration generated during the emission of the sound signal was made in according to the mentioned standards.

Accordingly, the impedance tube was made of one cylindrical metal tube with inner diameters of 3 cm and the total length of 97.2-cm. Samples of the material were placed in a sample holder with the length of 10 cm at one end of the straight tube. A 3-W loudspeaker was connected at the opposite end of the tube. A pair of 1/2 inch microphone from BSWA Company was mounted flush with the inner wall of the tube near the sample end of the tube. In addition, two microphones were connected to the frequency analyzer. To eliminate the error of microphones, they were calibrated by B&K calibrator at a frequency of 1000 Hz and 94 dB sound pressure.

Sound absorption measurement

After the building of impedance tube, the standard foam sample with thickness of 25 mm, received from the BSWA Technology Company was used to determine the feasibility and efficiency of the tube. In fact, the absorption coefficient of BSWA foam was measured by the impedance tube and VA-lab4 software in laboratory condition and was compared with standard graph from the BSWA company. according to the normal distribution of standard values and measured values, the comparisons were performed using Pearson correlation coefficient. After validating of system performance in accordance with relevant standard, seven test samples include closed cell polyurethane foam with 40 kg/m³ density, polystyrene (12 kg/m³), polyvinyl chloride (PVC) (1390 kg/m³), rubber (1200 kg/m³), mineral wool (20 kg/m³), carpet (1700 kg/m³), and glass (2100 kg/m³) were prepared in diameters of 30 mm and thicknesses of 25 mm and 30 mm. The samples were placed at the end of the impedance tube in front of the back plate.

For measurement of sound absorption coefficient was used from VA-lab4 software. To work with this software was selected the ISO standard and were determined the parameters including tube diameter and thickness of sample.

The tube has a number of fixed microphones, and the transfer function between two microphone positions was measured using a signal analysis system [Figure 1].^[7]

Thus, the complex pressure reflection coefficient as a function of frequency was obtained as equation 1:

$$r = \frac{H_{12} - H_1}{H_R - H_{12}} e^{2jk_0x_1} \tag{1}$$

Where H_{12} is the overall transfer function of the acoustic field, H_1 radiation transfer function, H_R reflected transfer function, X_1 is the distance between the sample and the further microphone location, and K_0 is the wave number.

Then, a normal sound absorption coefficient was determined using the following equation:^[5,7]

$$\alpha = 1 - |r|^2 \tag{2}$$

Finally, the effect of materials thickness on the absorption coefficient was measured, and the experimental results were showed in VA-lab4 software as graph in one-third octave band center frequencies.

RESULTS

Figure 2 shows the results of confirming the efficiency of impedance tube. There is a direct relationship between diagram of sound absorption coefficient measured in laboratory conditions and standard diagram of BSWA foam with correlation coefficient of 0.99 ($P < 0.001$) [Figure 2].

Table 1 shows a peak of absorption coefficient for the tested samples in two different thicknesses.

Material	Frequency (Hz)	Maximum of the sound absorption coefficients
Carpet 25	2500	0.97
Carpet 30	5000	0.95
Polyurethane foam 25	3150	0.1
Polyurethane foam 30	6300	0.14
Glass 25	3150	0.36
Glass 30	3150	0.2
Rubber 25	2000	0.03
Rubber 30	6300	0.05
Mineral wool 25	6300	0.97
Mineral wool 30	6300	0.97
Polystyrene 25	2500	0.59
Polystyrene 30	6300	0.3
PVC 25	2500	0.09
PVC 30	6300	0.13

PVC: Polyvinyl chloride

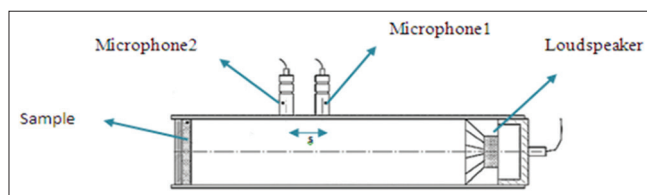


Figure 1: The transfer function method using two microphones impedance tube

According to the Table 1, the mineral wool and carpet had the highest absorption coefficient (0.97) and the rubber sample with 25 and 30 mm thickness had the minimum absorption (0.03 and 0.05, respectively) [Figure 3].

In mineral wool and carpet samples, when thickness and frequency increased, absorption coefficient was increased as well. However, the carpet sample with less thickness showed more sound absorption in the frequency range of 1500–3600 Hz [Figures 4 and 5].

Polystyrene sample with 25 mm thickness had the absorption coefficient higher than the same sample with thickness of 30 mm. In addition, in the glass sample, decrease of thickness increased the absorption coefficient in the frequencies of below 4500 Hz. Therefore, the peak of absorption coefficient of 25 mm glass sample was 0.36 that the amount was reduced to 0.2 in the 30 mm thickness. Furthermore, the difference between the peak absorption of two thicknesses in polystyrene sample was equal to 0.29 [Figures 6 and 7].

The samples such as rubber, PVC, and closed cell polyurethane foam had very low absorption coefficient in the frequency range of this experiment. In fact, these samples reflected sound and had a high reflection coefficient. Both samples showed that the reflection coefficient were similar between two thicknesses of 25 and 30 mm. The Figures 8 and 9 show the reflection coefficient of closed cell polyurethane foam and PVC in two different thicknesses.

DISCUSSION

All materials have some sound absorbing properties. Incident sound energy which is not absorbed must be reflected, transmitted, or dissipated. Material’s sound absorbing properties can be described as a sound absorption

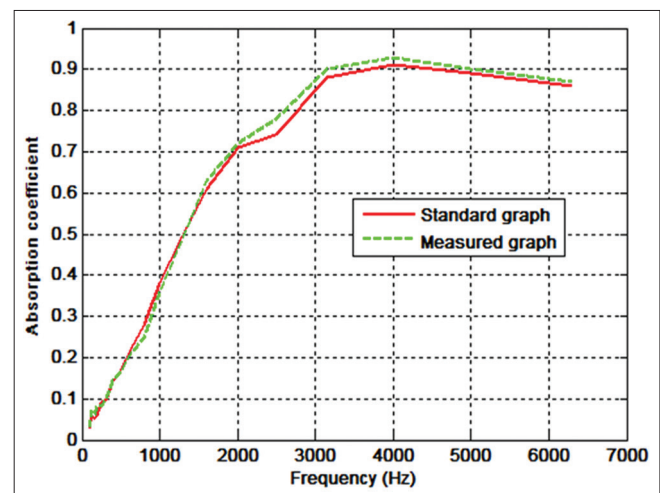


Figure 2: Comparison between standard absorption coefficient and measured values of 25-mm thick BSWA foam

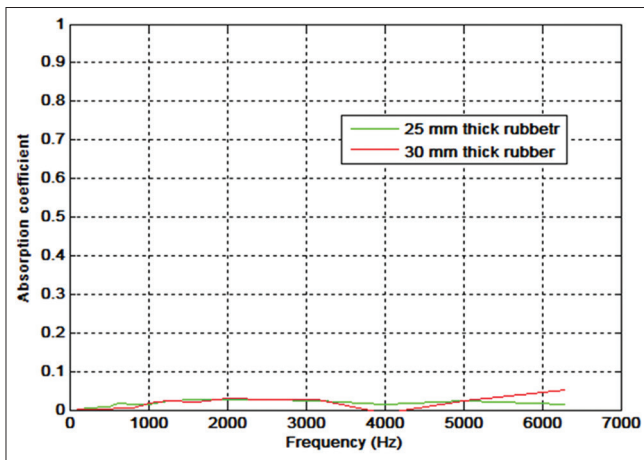


Figure 3: Comparison between absorption coefficients of 25 mm and 30 mm thick rubber

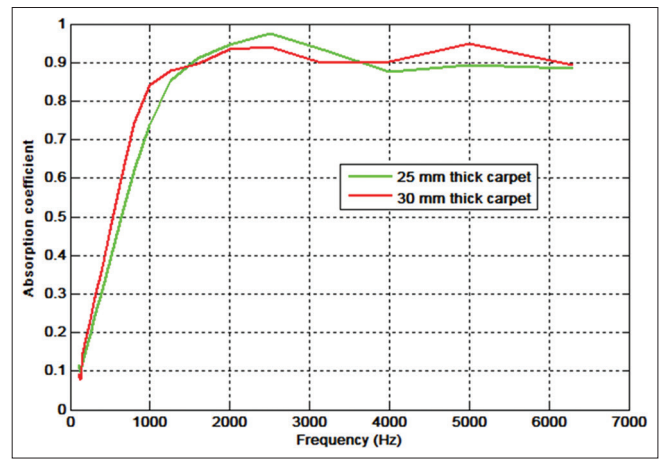


Figure 4: Comparison between absorption coefficients of 25 mm and 30 mm thick carpet

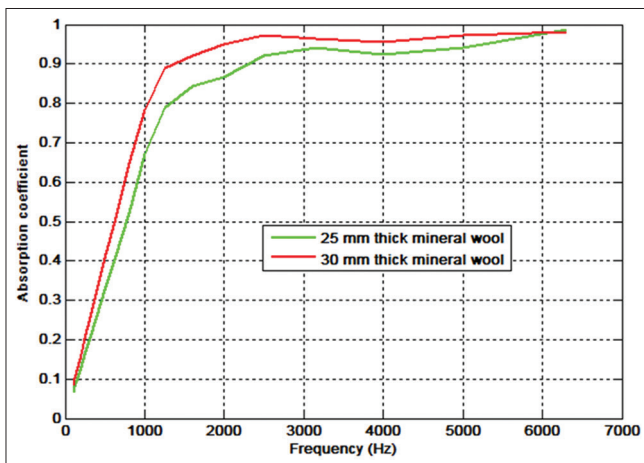


Figure 5: Comparison between absorption coefficients of 25 mm and 30 mm thick mineral wool

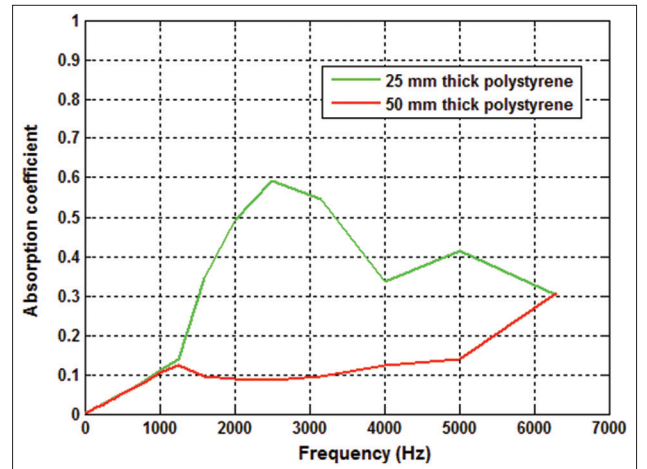


Figure 6: Comparison between absorption coefficients of 25 mm and 30 mm thick polystyrene

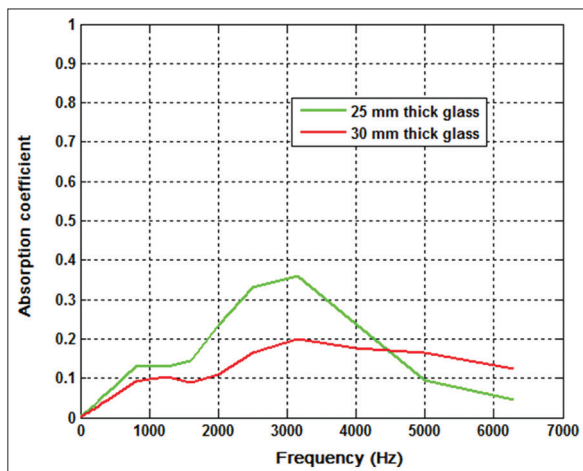


Figure 7: Comparison between absorption coefficients of 25 mm and 30 mm thick glass

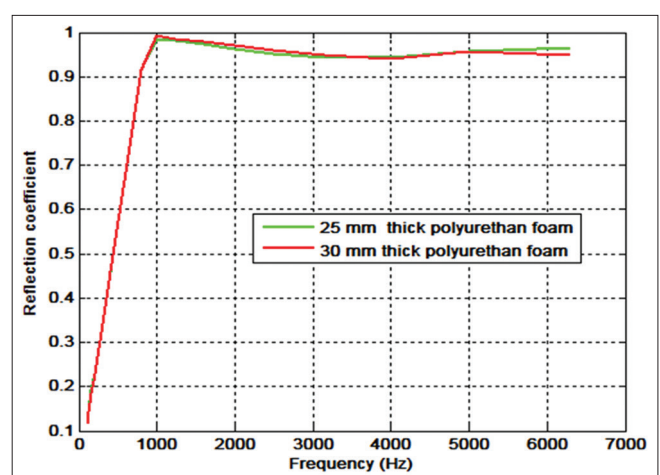


Figure 8: Comparison between reflection coefficients of 25 mm and 30 mm thick closed cell polyurethane foam

coefficient in particular frequency range. The experiments showed that among the tested materials, carpet samples and mineral wool had the highest absorption coefficient,

while the closed cell polyurethane foam, PVC, and rubber had a lower sound absorption. The obtained results showed that porous materials had a higher absorption

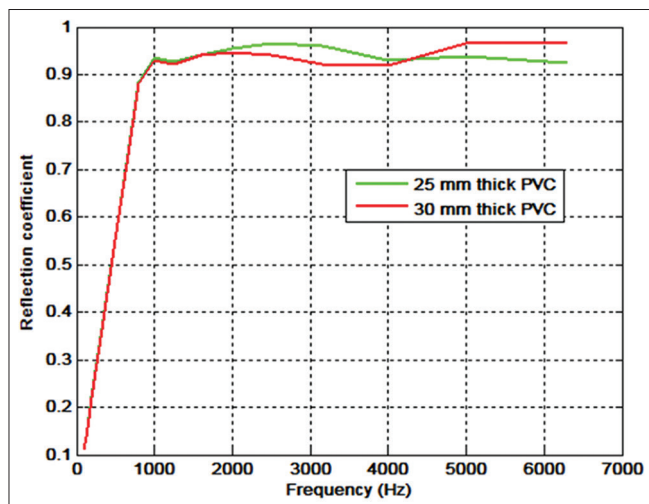


Figure 9: Comparison between reflection coefficients of 25 mm and 30 mm thick polyvinyl chloride

coefficient than other materials. In addition, the thickness of polystyrene and glass sample showed the significant effect on absorption coefficient. In fact, polystyrene in frequencies above of 250 Hz and glass in frequencies of below 4500 Hz with less thickness had higher sound absorption. In the mineral wool sample, the absorption rate was increased with increasing thickness. In addition, for carpet sample, the absorption coefficient was increased in all frequencies when thickness increased (except of 1500–3600 Hz frequencies).

Sikora and Turkiewicz measured the absorption coefficient of mineral wool at different thicknesses and obtained that sound absorption at high frequencies were higher than low frequencies. Furthermore, sound absorption was increased in higher thicknesses that these results are similar to this study.^[13] In another study, Hung and Huang reported that wasted rubber particles had lower sound absorption at higher frequencies.^[14] Lim *et al.* reported that increment of the thickness can be seen to significantly improve the absorption coefficient.^[15] Norton and Karczub reported that the porous or fibrous materials generally had good sound absorbing characteristics at high frequencies (> 1000 Hz), with a rapid deterioration at low frequencies that the results are similar to this study.^[16]

CONCLUSION

According to the results of this study can be determined the absorption coefficient of materials with lowest cost and highest accuracy by impedance tube and transfer function

method to achieve the desired results of noise control in environment and industry.

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Conflicts of interest

There are no conflicts of interest.

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