Research article

# The noise absorption prediction of a combined and independent absorber under different conditions and at different frequencies, using the new Engineering Noise Control Software (ENC)

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## ARTICLE INFO

## ABSTRACT

Noise is one of the most harmful factors in the work environment, which is very important to control. There are various techniques to achieve this goal. One of the most important of them is the use of noise absorbers. Absorbent materials are often used to counteract the effects of reflected noise from hard surfaces and reduce their level. This is an experimental-applied study conducted in the physical factor laboratory of the Faculty of Health. The purpose was to predict the Noise absorption rate of combined and independent absorbers under different conditions and frequencies using the new ENC (engineering noise control) software. The sound absorption determination was carried out in 5 stages, including sound frequency analysis for the source, measurement of the dominant frequency, measurement of the absorption coefficient of absorbent materials in different conditions, measurement of the limit frequency (peak frequency of noise absorption) and comparison of the software results with the findings of the impedance tube in Real conditions. The best absorption mode for combined and independent absorbents is using a 5 cm rock wool absorbent with a 2 cm thick air layer behind it without a polyurethane absorbent layer and a 10 cm wide rock wool absorbent with a 1 cm air layer behind it without polyurethane layer. A polyurethane layer on the stone wool absorber decreased the amount of noise absorption for high frequencies. The results obtained from the best absorption conditions in the ENC software were consistent with the findings from the impedance tube device in real situations. The results of this study showed that suitable and optimal conditions of sound absorption could be achieved by using the ENC software, correct design, use of suitable absorbers, changes in the physical parameters of the absorber, and the use of a combined absorber.

## 1. Introduction

Noise is one of the significant hazards in today's world [1, 2]. It entails irregular waves that are unpleasant, unwanted, and typically inevitable, with no meaningful relationship between their amplitude, frequency, and length [3]. It also involves a large number of people. Research shows that about 600 million workers worldwide are exposed to work-related noise beyond the standard limits [4]. Based on scientific estimates and comparisons made with similar countries, it is projected that about 2 million workers in Iran have regular contact with work-related noise [5].

Nowadays, noise control applications are a significant priority in different industries and environments [6, 7]. Noise control in industry and the work environment is critical for individuals' comfort and efficiency. Various techniques are utilized to control noise in industrial settings, one of which is noise absorption materials [8]. Using noise-absorbing materials is the transmission path's most common noise control method. Absorbent materials are often used to deal with the effects of sound reflected from hard surfaces [9]. Indeed, as noise transmits through porous materials, the absorbed energy is transformed into heat due to the friction between sound waves and porous cell walls. In other

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words, when sound waves are transmitted through porous materials, they are transformed into heat, hence sound absorption by the acoustic materials [10]. Rock wool and polyurethane are the most commonly used noise absorbers, especially dissipative silencers. Many parameters affect the efficiency of noise absorbers; each change of these parameters changes the amount of absorption for different frequencies in some way. Based on Williams et al. study, absorption mufflers are more effective at medium to high frequencies, and Rock wool absorbers are more suitable for sound absorption at high frequencies. But at low frequencies, it can be improved by changes in parameters such as the thickness of the noise absorber, the thickness of the air layer behind the back, and the density [11]. As shown in Zhang et al. and Yousefi et al. studies, Increasing the thickness of a rock wool absorber can increase sound absorption at low frequencies [12, 13]. Also, increasing the thickness of the air layer in the Seddeq study and Denia study increases the noise absorption coefficient at lower frequencies [14, 15]. In noise absorption by an acoustic material, part of the sound is lost when sound waves encounter a particular surface. This lost energy is transformed into heat [16]. Lower absorption coefficients of internal surfaces will lead to sound reverberation, transforming such surfaces into secondary sound sources [17]. The absorption coefficient can be measured using specific techniques such as reverberation room and impedance tubes. In addition, ENC Software, a software program, can be exploited to measure the absorption coefficient. All these techniques are capable of yielding information about acoustic features of materials, e.g., noise absorption coefficient [18]. Since many parameters affect the amount of sound absorption by the absorber in absorption silencers, experimental testing of all these parameters is not possible because it is difficult to control sound at low frequencies using absorption silencers. Thus, the current study aimed at 1. Measuring the dominant frequency of the noise source (fan) without an absorber (or absorption silencer) and reaching the optimal frequency of noise absorbent materials. 2. Prediction of the sound absorption coefficient of combined and independent absorbers under different conditions. 3. Comparing the noise absorption results obtained from the software with the results obtained from the impedance tube, and as a result, introducing suitable and new software for measuring the noise absorption coefficient of noise absorbent materials. 4. Coming up with a condition in which the absorber's functionality in absorbing frequencies, especially low frequencies, improves, hence making it unnecessary to run experimental tests.

## 2. Method

### 2.1. Research design

An experimental applied research design was adopted in this study, which was carried out in the laboratory of physical factors of the Faculty of Health with the fan on (The reason for using a fan in this study is to determine the best sound absorption conditions based on frequency analysis of a real source and use the results to design a silencer for the desired fan in the future). The noise absorption Prediction of a combined and independent absorber under different conditions and at different frequencies, using the new Engineering Noise Control Software (ENC)[1]. ENC software has seven main modules, and each module is for specific purposes (such as fundamentals and criteria calculation (module 1), sound sources, sound propagation and sound power (Module 2), room acoustics and sound absorption (Module 3), reactive and designed dissipative mufflers (Module 5), etc.). In this study, module 3 was used to evaluate the room acoustics and sound absorption. By entering the properties of different materials into the software, their absorption properties are determined. The amount of noise absorption for the combined and independent absorber, with the

purpose of noise control for different conditions, was done in 5 stages, including sound frequency analysis for the source, measurement of the dominant frequency, measurement of the absorption coefficient of absorbent materials in different conditions, measurement of the limit frequency and comparison of the findings of the software with the results of the impedance tube in actual situations. In short, the steps of this study include:

1- measuring the dominant frequency of the sound source using frequency analysis, 2- measuring the limit frequency (peak frequency of sound absorption) of absorbent materials using ENC software with changes in parameters. The physics of the combined and independent absorber, 3- The comparison of the best sound absorption mode for all frequencies with the results obtained from the impedance tube in actual conditions. We describe the order of the work steps in detail in the following: Figure 1 shows a schematic diagram of the experiment setup based on the research design. And also, the steps for doing the work are described at following:

### 2.2. Analyzing ambient frequency (fan's noise) without absorber

Initially, ambient frequency analysis was carried out to assess the dominant frequency in the environment without applying an absorber. Frequency analysis was accomplished based on the ISO11820 standard in the central octave band frequencies (8000HZ63/5HZ) using a Cell-450 sound level meter equipped with nose cone [19]. Frequency analysis was performed for an octave band (In the octave band, frequencies are doubled in each step. such as 63.5 Hz and the next frequency is 125 Hz and the next 250 Hz, ... up to 8000 Hz) in which the upper limit frequency is twice the lower limit frequency. It should be noted that for controlling the sound of noise sources by a silencer, frequency analysis is necessary. Hence, it is possible to know the sound pressure levels at different octave band frequencies and the dominant frequency. Therefore, the best sound absorption condition can be selected.

### 2.3. Measurement of dominant frequency

The dominant frequency is the frequency with the highest sound pressure level (sound energy). The dominant frequency was obtained through frequency analysis. When the dominant frequency of the noise source is equal to the limit frequency of the absorber material, the best condition will be obtained.

### 2.4. Measuring the absorption coefficient of combined and independent adsorbents in different conditions using ENC software

In this stage, the absorption coefficient of combined and independent absorbent materials was gauged in various frequencies and under different conditions using ENC [20]. At first, the absorption coefficient of 5 cm thick rock wool and 10 cm thick rock wool was measured with no air layer behind it and no absorber layer. Then, the absorption coefficient of 5 cm thick rock wool was calculated with a 1 cm thick air layer and no absorber layer. After that, the absorption coefficient of 5 cm thick rock wool was assessed with a 2 cm thick air layer and no absorber layer on it. The following stages were similarly carried out under various conditions:

At first, the absorption coefficient of 5 cm thick rock wool and 10 cm thick rock wool was measured under various conditions as follow:

1. The absorption degree rock wool absorber with a thickness of 5 cm with no air layer behind it and no absorber layer (No. 1 absorber)
2. The absorption degree rock wool absorber with a thickness of 10 cm with no air layer behind it and no absorber layer (No. 2 absorber)
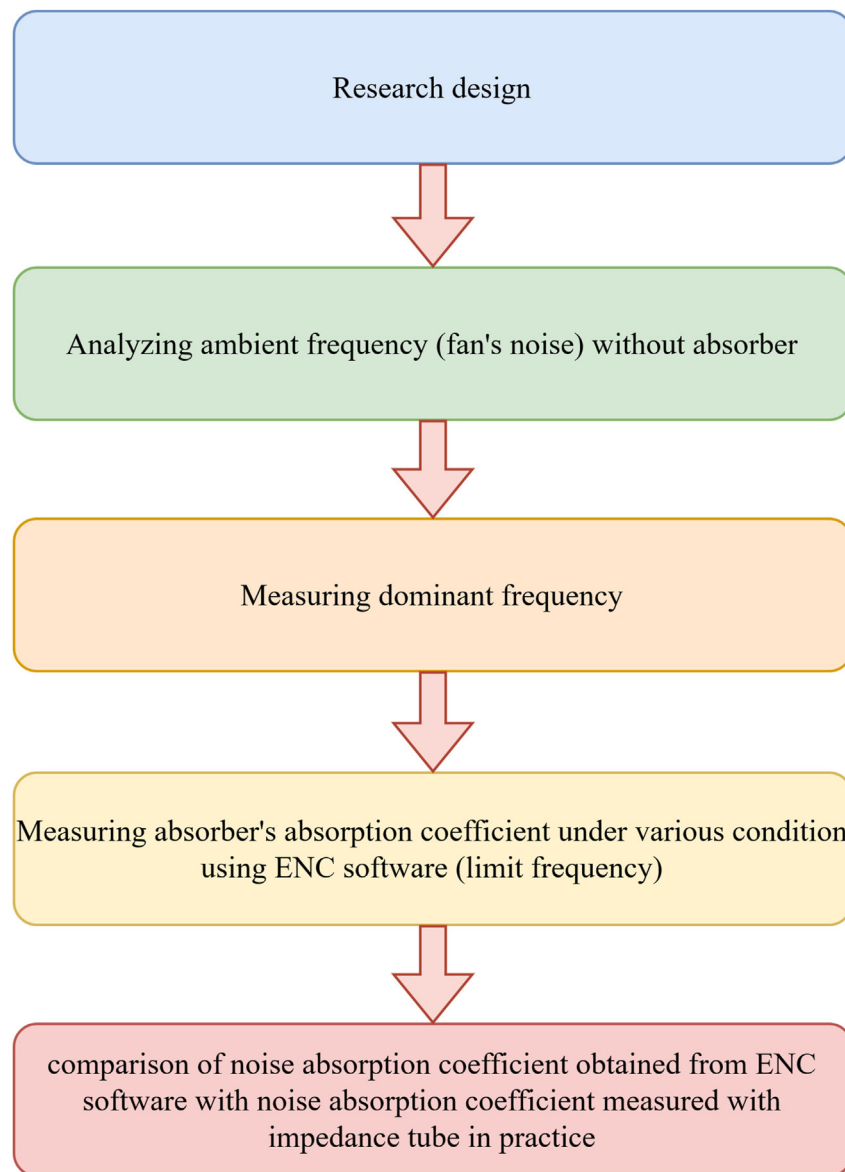
**Figure 1.** Schematic diagram of the experiment setup.

3. The absorption degree rock wool absorber with a thickness of 5 cm with a 1 cm thick air layer and no absorber layer (No. 3 absorber)

4. The absorption degree rock wool absorber with a thickness of 10 cm with a 1 cm thick air layer and no absorber layer (No. 4 absorber)

5. The absorption degree rock wool absorber with a thickness of 5 cm with a 2 cm thick air layer and no absorber layer (No. 5 absorber)

6. The absorption degree rock wool absorber with a thickness of 10 cm with a 2 cm thick air layer and no absorber layer (No. 6 absorber)

7. The absorption degree of 5 cm thick rock wool with a 1 cm thick air layer behind it and a 0.05 cm thick polyurethane layer on it (No. 7 absorber)

8. The absorption degree of 10 cm thick rock wool with a 1 cm thick air layer behind it and a 0.05 cm thick polyurethane layer on it (No. 8 absorber)

9. The absorption degree of 5 cm thick rock wool with a 2 cm thick air layer behind it and a 0.05 cm thick polyurethane layer on it (No. 9 absorber)

10. The absorption degree of 10 cm thick rock wool with a 2 cm thick air layer behind it and a 0.05 cm thick polyurethane layer on it (No. 10 absorber)

11. The absorption degree of 5 cm thick rock wool with a 1 cm thick air layer behind it and a 0.1 cm thick polyurethane layer on it (No. 11 absorber)

12. The absorption degree of 10 cm thick rock wool with a 1 cm thick air layer behind it and a 0.1 cm thick polyurethane layer on it (No. 12 absorber)

13. The absorption degree of 5 cm thick rock wool with a 2 cm thick air layer behind it and a 0.1 cm thick polyurethane layer on it (No. 13 absorber)

14. The absorption degree of 10 cm thick rock wool with a 2 cm thick air layer behind it and a 0.1 cm thick polyurethane layer on it (No. 14 absorber)

Finally, the best adsorption conditions obtained from ENC software using an Impedance tube (in the case of rock wool with a density of 120 kg/m$^3$) with ISO 10534-2 standard were tested in practice. Based on the noise source's dominant frequency, it is necessary to reach a condition

that the critical frequency in absorber materials be close or equal to the dominant frequency of the noise source.

### 2.5. Measuring limit frequency (peak frequency of noise absorption)

In the next phase, the limit frequency (i.e., the frequency in which the highest degree of absorption is observed) was gauged under various conditions. These values are observed for each table in the findings. The noise absorption part is observed in ENC software (Appendix A, Figure A1). It should be noted that this part of the software is used to predict the noise absorption coefficient of different absorbers with changes in the physical parameters of the noise absorbers. The following path illustrates how this part can be accessed (option Module 3 porous material absorbers).

### 2.6. Ethical code

The present study has been approved by the ethic committee of Kerman University of Medical Sciences by code number of http://ethics.research.ac.ir/IR.KMU.REC.1400.083.

### 3. Results

#### 3.1. The amount of ambient frequency (fan's noise) without absorber

Ambient frequency analysis was accomplished based on the ISO11820 standard in the central octave band frequencies (8000HZ63/5HZ) using a Cell-450 Sound Level Meter, and the data were analyzed using ENC Software (Figure 2). As indicated in Figure 2, the fan's noise is higher in low frequencies. It was also observed that the dominant frequency was 63 Hz.

### 3.2. The degree of rock wool's absorption in various conditions as measured by ENC software

#### 3.2.1. Comparison of Absorption coefficient of no. 1 and no. 2 absorbers

According to Figure 3, the degree of noise absorption is insignificant for rock wool absorber with a thickness of 5 cm in low frequencies. In contrast, the absorption rate goes up as frequency increases. Under this condition, the frequency limit is 8000 Hz in the current situation, the absorption coefficient for rock wool absorber with 10 cm thickness, compared to the degree of noise absorption of rock wool absorber with a thickness of 5 cm, for frequencies of 31.5, 63 and 125 Hz is much higher, for frequencies of 250, 500 and 2000 Hz lower, slightly higher for the frequency of 1000 Hz, and frequencies of 4000 and 8000 Hz is similar. The frequency limit under this condition was 8000 Hz.

#### 3.2.2. Comparison of the absorption coefficient of no. 3 and no. 4 absorbers

As illustrated in Figure 4, in the current condition, the presence of an air layer for rock wool absorber with a thickness of 5 cm significantly increases noise absorption in low frequencies, has a moderate influence on noise absorption in middle range frequencies, and does not change the degree of noise absorption in high frequencies. The limit frequency was found to be 8000 Hz in the current condition, the absorption coefficient for rock wool absorber with 10 cm thickness, compared to the situation in which the rock wool was 10 cm thick and had no air layer behind it or no absorber layer on it, the degree of absorption went down for the frequencies of 31.5 and 63 Hz, slightly grew for the middle range frequency of 500 Hz, slightly declined for the medium range frequencies of 125 and 250 Hz, and remained constant for the frequencies of 1000, 2000, 4000, and 8000 Hz. The limit frequency under this condition was found to be 8000 Hz.

#### 3.2.3. Comparison of Absorption coefficient of no. 5 and no. 6 absorbers

Based on Figure 5, in the current condition, for rock wool absorber with a thickness of 5 cm, a significant amount of absorption was observed for low frequencies. The absorption rise was especially considerable for the dominant frequency (63 Hz). The limit frequency under this condition was found to be 8000 Hz in the current situation, the absorption coefficient for rock wool absorber with 10 cm thickness, with a 2 cm thickness air layer behind it, compared to the condition in which the rock wool was 10 cm thickness, with no air layer behind it, had a slight increase for the frequencies of 31.5 and 500 Hz, a slight decrease for the frequencies of 125 and 250 Hz, and remained constant for the frequencies of 63, 1000, 2000, 4000, and 8000 Hz. Also, the degree of noise absorption in this situation for the dominant frequency (63 Hz) was lower than the thickness of the air layer by 1 cm. The limit frequency in this condition was 8000 Hz.
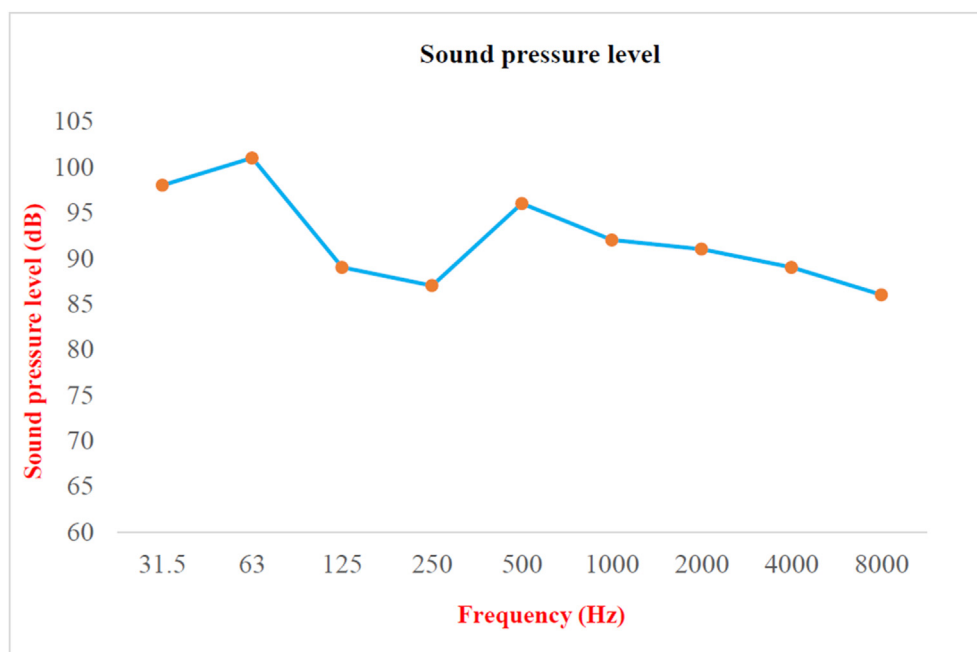


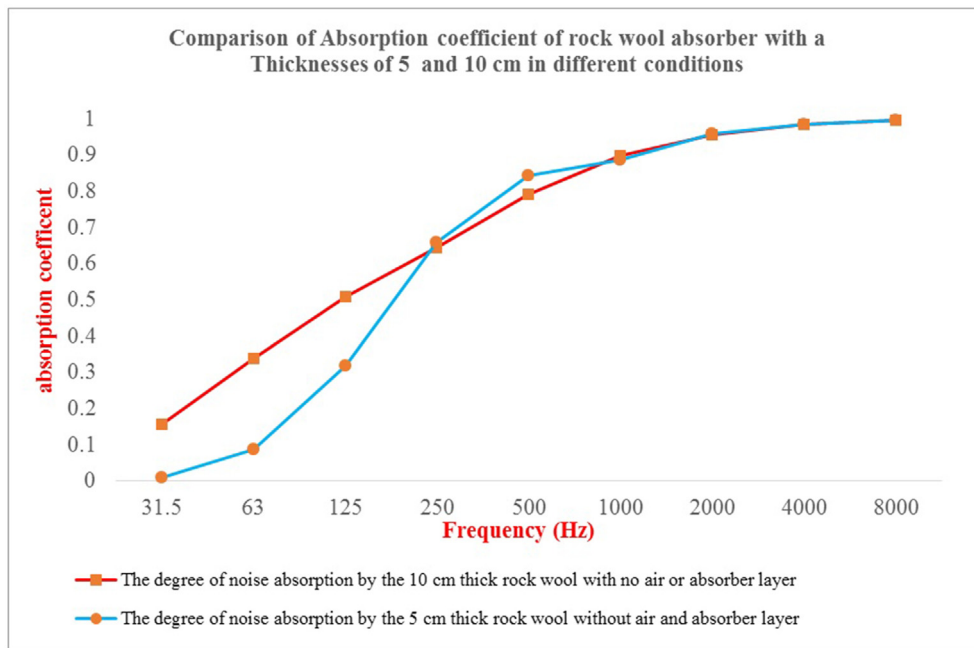**Figure 2.** Ambient (fan's) noise in various frequencies.

**Figure 3.** Comparison of Absorption coefficient of rock wool absorber with a Thickness of 5 cm and rock wool absorber with a thickness of 10 cm, with no air layer behind them and no absorber layer of polyurethane on them.
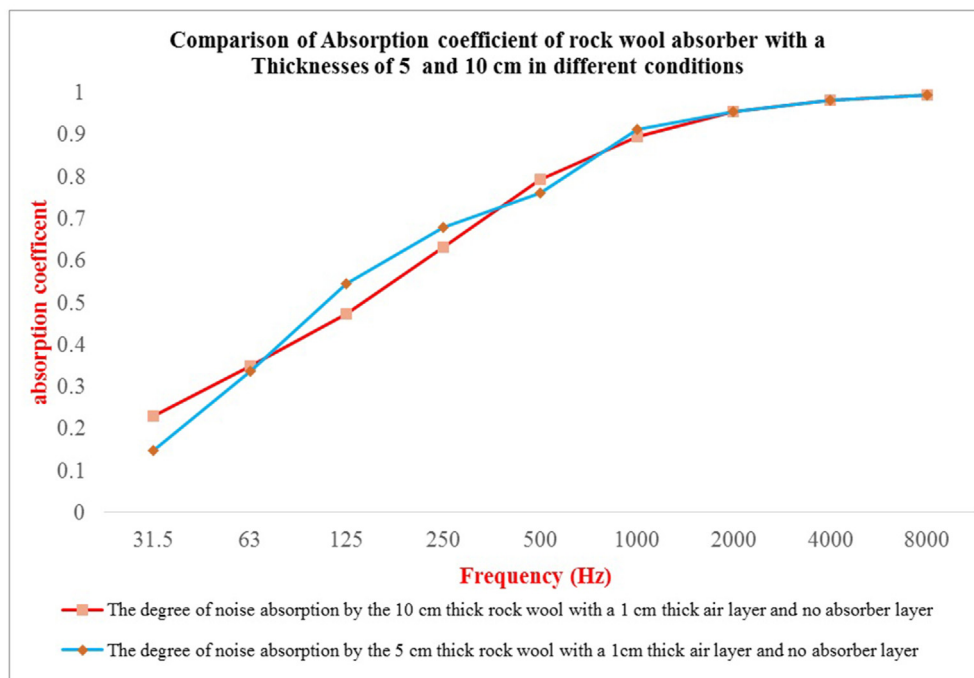


**Figure 4.** Comparison of Absorption coefficient of rock wool absorber with a thickness of 5 cm and rock wool absorber with a thickness of 10 cm, with a 1 cm thickness air layer behind them and no absorber layer of polyurethane on them.

### 3.2.4. Comparison of the absorption coefficient of no. 7 and no. 8 absorbers

s displayed in Figure 6, under this condition, for rock wool absorber with a thickness of 5 cm, a significant increase in the amount of absorption was observed for low frequencies (This rise was, however, less significant in comparison with the degree of absorption without the presence of an absorber layer of polyurethane). In general, the presence of air layer and polyurethane led to a considerable increase in noise absorption for low frequencies, an insignificant increase or even reduction in the noise absorption for middle-range frequencies, and a

significant decline in noise absorption for high frequencies. The limit frequency under this condition was found to be 1000 Hz in the current state, the absorption coefficient for rock wool absorber with 10 cm thickness, with a 2 cm thickness air layer behind it, compared to the situation described in 3.2.1, slightly went up for the frequencies of 31.5, 63, 250, 500, and 1000 Hz (For low frequencies of 31.5 and 63 Hz, this rise was bigger than that for the condition in which no absorber layer of polyurethane or air layer was applied), slightly declined for the frequencies of 125 and 2000 Hz, and considerably decreased for the
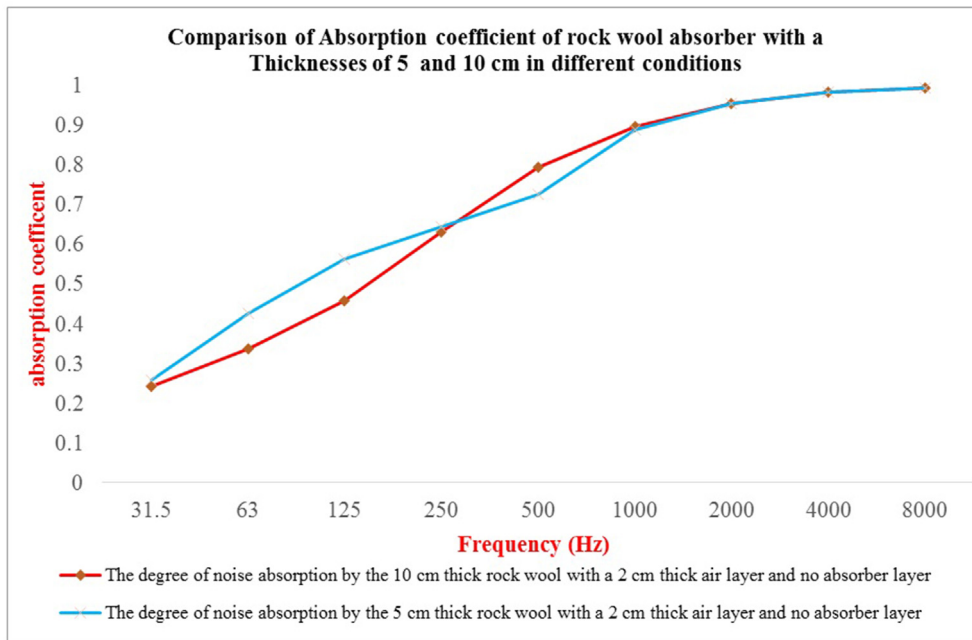
**Figure 5.** Comparison of Absorption coefficient of rock wool absorber with a thickness of 5 cm and rock wool absorber with a thickness of 10 cm, with a 2 cm thickness air layer behind them and no absorber layer of polyurethane on them.
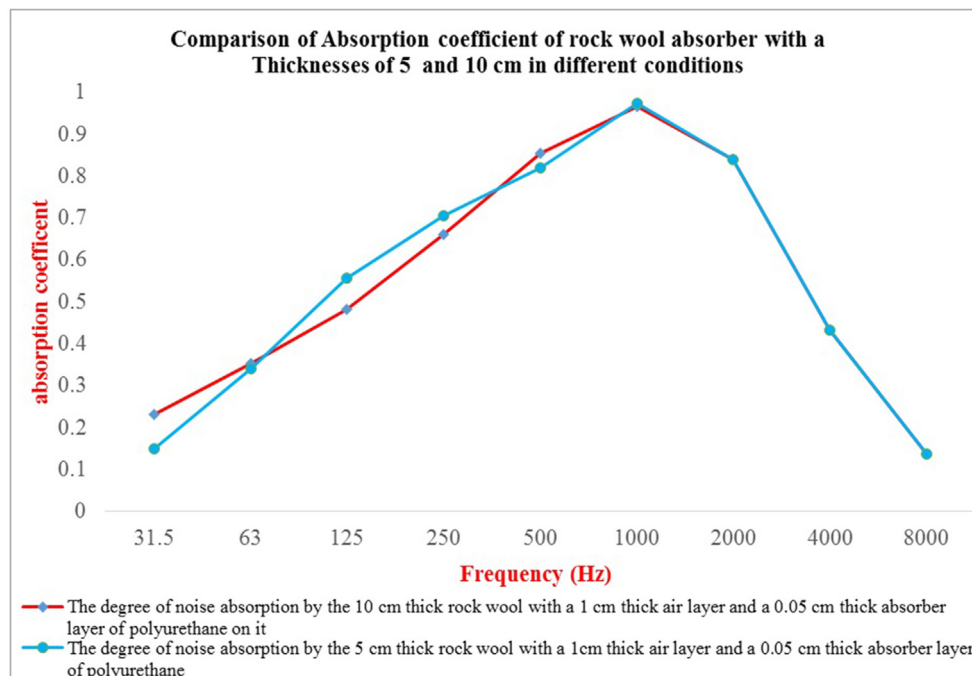


**Figure 6.** Comparison of Absorption coefficient of rock wool absorber with a thickness of 5 cm and rock wool absorber with a thickness of 10 cm, with a 1 cm thickness air layer behind them and a 0.05 cm thickness absorber layer of polyurethane on them.

frequencies of 4000 and 8000 Hz. The limit frequency in this condition was found to be 1000 Hz.

### 3.2.5. Comparison of Absorption coefficient of no. 9 and no. 10 absorbers

As indicated in Figure 7, under this condition, for rock wool absorber with a thickness of 5 cm, the absorption coefficient significantly grew for low frequencies (This rise was, however, smaller than the condition in which no absorber layer of polyurethane was used). The limit frequency under this condition was 1000 Hz for a rock wool absorber with a thickness of 10 cm; noise absorption rises in low frequencies, slightly go

up or even declines in middle-range frequencies, and measurably goes down in high frequencies. Under this condition, the limit frequency was found to be 1000 Hz.

### 3.2.6. Comparison of the absorption coefficient of no. 11 and no. 12 absorbers

As illustrated in Figure 8, under this condition, for rock wool absorber with a thickness of 5 cm, the absorption coefficient significantly grew for low frequencies (This rise was, however, smaller than the condition in which no absorber layer of polyurethane was used or the thickness of the
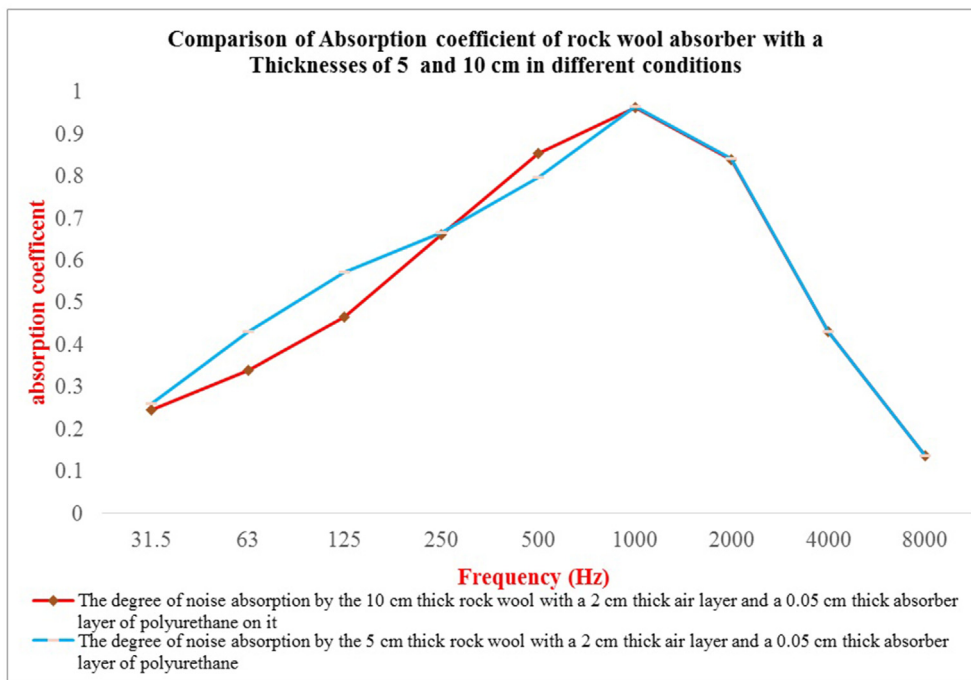
**Comparison of Absorption coefficient of rock wool absorber with a Thicknesses of 5 and 10 cm in different conditions**



**Figure 7.** Comparison of Absorption coefficient of rock wool absorber with a thickness of 5 cm and rock wool absorber with a thickness of 10 cm, with a 2 cm thickness air layer behind them and a 0.05 cm thickness absorber layer of polyurethane on them.

polyurethane layer was smaller). The limit frequency under this condition was found to be 1000 Hz. And for rock wool absorbers with a thickness of 10 cm, due to the simultaneous presence of the air layer and absorber layer of polyurethane, noise absorption rises for low frequencies, slightly goes up or even declines for the middle range, and considerably decreases for high frequencies. The limit frequency was found to be 500 Hz under this condition.

*3.2.7. Comparison of the absorption coefficient of no. 13 and no. 14 absorbers*

According to Figure 9, under this condition, for rock wool absorber with a thickness of 5 cm, the absorption coefficient significantly went up for low frequencies (This rise was higher for the frequencies ranging from 31.5 through 1000 Hz in comparison with the condition wherein rock wool was 5 cm thick, and there was a 2 cm thick air layer and no absorber
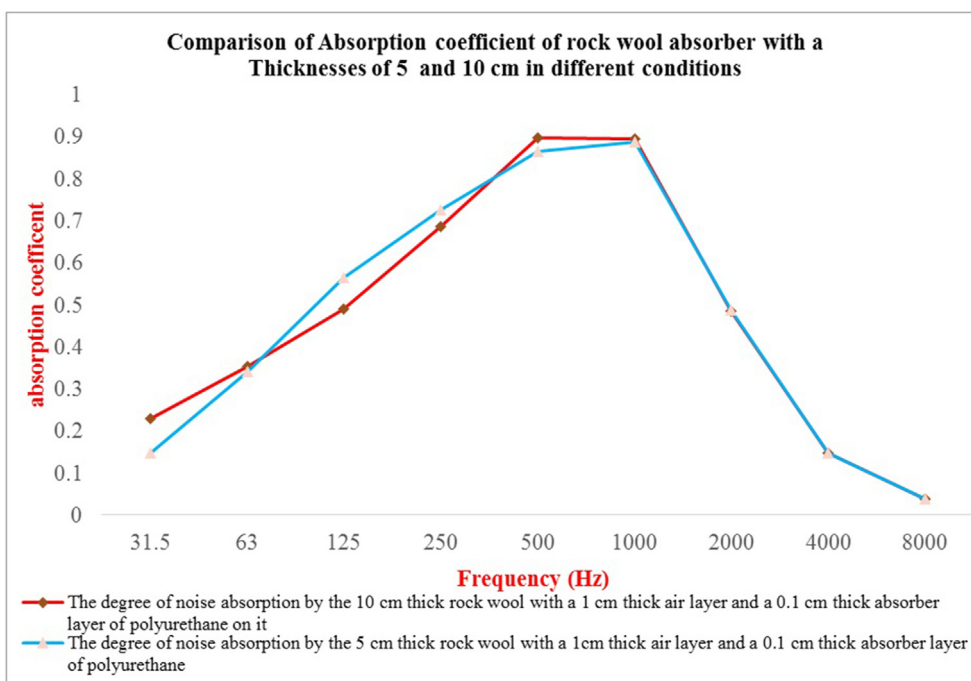
**Comparison of Absorption coefficient of rock wool absorber with a Thicknesses of 5 and 10 cm in different conditions**



**Figure 8.** Comparison of Absorption coefficient of rock wool absorber with a thickness of 5 cm and rock wool absorber with a thickness of 10 cm, with a 1 cm thickness air layer behind them and a 0.1 cm thickness absorber layer of polyurethane on them.
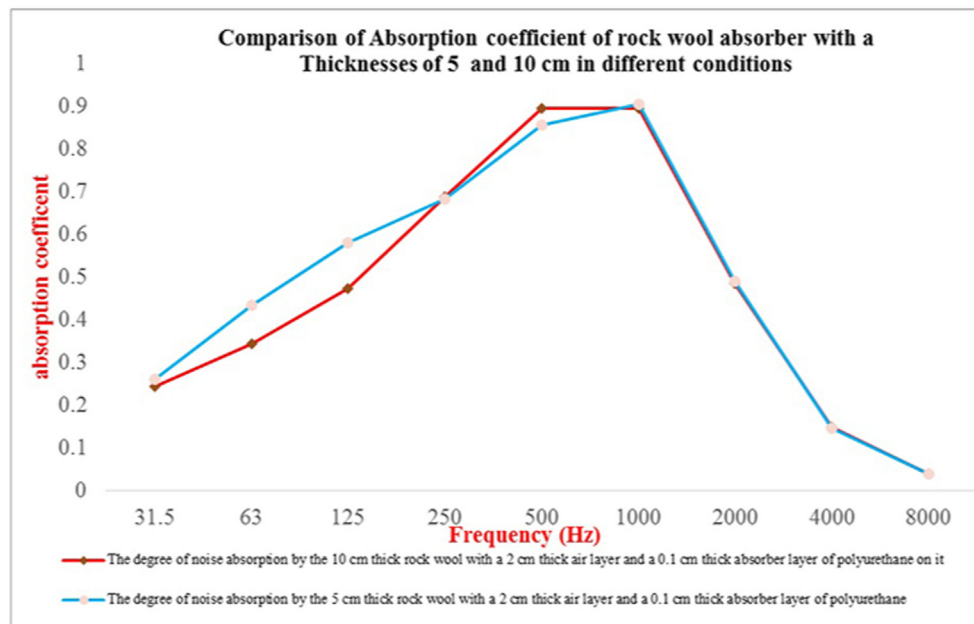
**Figure 9.** Comparison of Absorption coefficient of rock wool absorber with a thickness of 5 cm and rock wool absorber with a thickness of 10 cm, with a 2 cm thickness air layer behind them and a 0.1 cm thickness absorber layer of polyurethane on them.

layer of polyurethane. Moreover, the growth was higher for frequencies ranging from 31.5 to 500 Hz compared to the condition in which the absorber layer of polyurethane was less thick). The limit frequency was found to be 1000 Hz. And for rock wool absorbers with a thickness of 10 cm, the noise absorption was higher for low frequencies and more negligible for frequencies equal to or greater than 1000 Hz. Overall, the simultaneous application of polyurethane air layer and absorber layer increased noise absorption in low frequencies, slightly rose or even declined noise absorption in middle range frequencies, and significantly decreased in high frequencies. Under this condition, the limit frequency was 500 and 1000 Hz.

### 3.2.8. Comparison of the absorption coefficient of 5 and 10 cm thick rock wool in the absence of an air layer behind them and the presence of 0.05 and 0.1 thick absorber layers of polyurethane on them

For most of the frequencies, the degree of noise absorption in this condition was similar to that with and without air layer.

### 3.3. Selecting the best condition of noise absorption

According to the obtained results in Section 3.2, considering the rock wool with a thickness of 5 cm, the best condition for noise absorption was observed when the air layer behind it was 2 cm thick, and there was no polyurethane layer on it. The 5 cm thick rock wool with no air layer behind it had a minimal absorption rate in low frequencies. In contrast, with a 2 cm thick air layer behind it, this absorber absorbed a considerable degree of noise in low frequencies. Overall, the 5 cm thick rock wool had good noise absorption in all frequencies under this condition. Furthermore, as the thickness of the polyurethane layer increased, the limit frequency declined.

On the other hand, if the absorber layer of polyurethane is used on rock wool, the noise absorption in low frequencies slightly improves, while it significantly declines for high frequencies. Concerning 10 cm thick rock wool, the best condition for noise absorption was observed when the thickness of the air layer was 1 cm, and there was no polyurethane layer on the rock wool. Moreover, the 10 cm thick rock wool with no air layer behind it had a significantly lower absorption rate in low frequencies (with the amount of absorption in this condition being higher than that of the condition in which the rock wool had a thickness

of 5 cm). However, when the 1 cm air layer was applied behind the rock wool, the degree of absorption considerably rose in low frequencies. Overall, the 10 cm thick rock wool had an acceptable absorption rate in all frequencies under this condition.

Additionally, with the rise of polyurethane thickness, the limit frequency declined. Applying polyurethane on rock wool under this condition improves the abruption rate in low frequencies. It significantly decreases noise absorption in high frequencies (Figures 10 and 11).

### 3.4. Comparison of the best mode of noise absorption obtained from ENC software with the amount of noise absorption obtained from the impedance tube in experimental conditions

According to Figure 12, the best noise absorption mode obtained from the ENC software for all frequencies (which includes an independent rock wool absorber with a thickness of 5 cm and an air layer with a thickness of 2 cm behind it and for the rock wool absorber independent with a thickness of 10 cm and a layer of air with a thickness of 1 cm behind it) was compared with the amount of noise absorption obtained from the impedance tube under experimental conditions. It was found that the prediction results of the sound absorption rate of ENC software are very close to the results obtained from the impedance tube.

### 4. Discussion

This study was conducted to predict the noise absorption rate of combined and independent absorbers under different conditions and at different frequencies using the new ENC (Engineering Noise Control) software. The results indicated that the absorption rate differed depending on the thickness of the absorber, the layer of air, and the polyurethane layer. The rise of rock wool and air layer thickness would result in improved absorption in low frequencies. The highest degree of noise absorption was recorded when the rock wool was 5 cm thick, there was a 2 cm thick air layer behind it, and there was no absorber layer of polyurethane. Regarding the rock wool that was 10 cm thick, the best absorption condition was registered when the air layer was 1 cm thick and there was no absorber layer of polyurethane on the rock wool. A polyurethane layer on the rock wool would significantly decrease noise absorption in high frequencies and a negligible rise in absorption in low
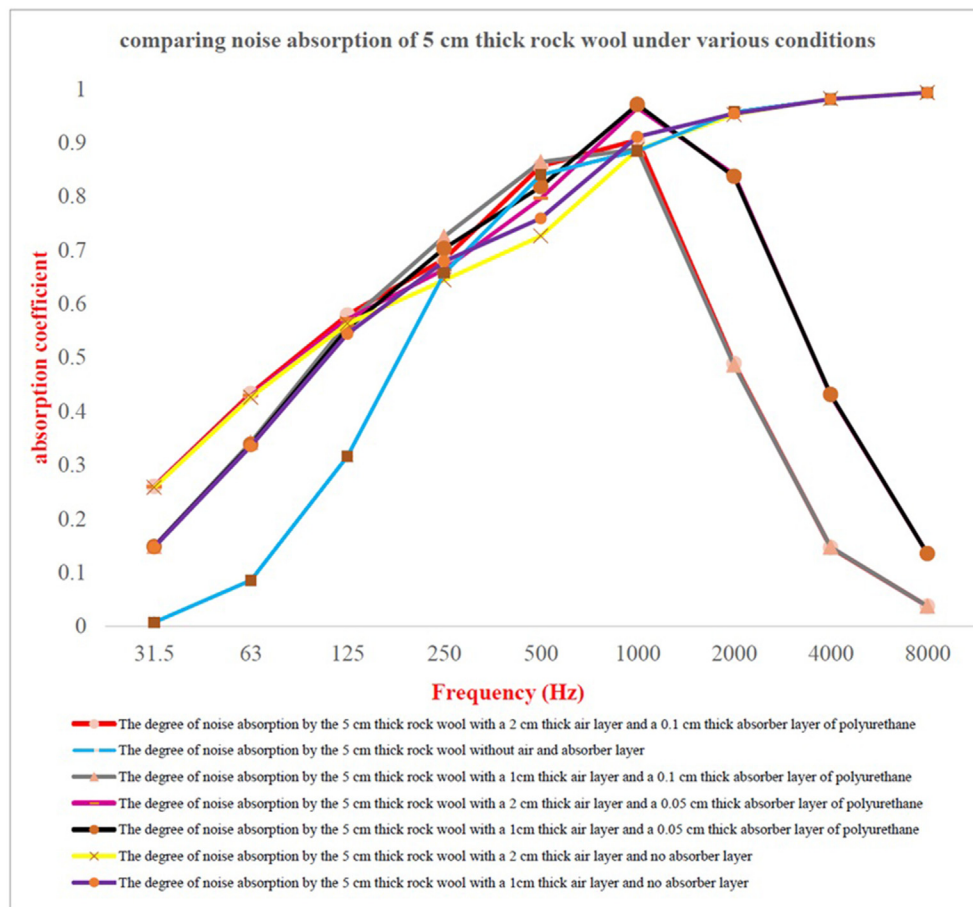
**Figure 10.** Comparing absorption coefficients of 5 cm thick rock wool.

frequencies. Raising the thickness of the polyurethane layer would lead to a further reduction in noise absorption rate in high frequencies (Figures 10 and 11). It should be noted that the results obtained from the best adsorption conditions in ENC software were very consistent with the findings obtained from the impedance tube device (in the conditions of using rock wool adsorbent with a density of 120 kg/m3).

In the study of Mohammadi et al., Which was performed to evaluate the sound absorption properties of open-cell polyurethane foams modified with rock wool fibers, the highest sound absorption efficiency for the modified absorber was in the range between 500 and 4800 Hz, While the absorption coefficient did not improve significantly at frequencies above 4800 Hz [21]. In the present study, the highest sound absorption was observed in the presence of rock wool, polyurethane foam, and air layer at frequencies of 500–3000 Hz.

In a study, Sengupta et al. investigated the effect of thickness and compaction of a natural fiber set on noise reduction. The study's results showed that with increasing frequency, sound energy absorption initially increases for all fibers. After reaching its maximum in the range of 3000–4000 Hz, the absorption decreases by 10–20%. It was also found that with increasing density of filling fiber, the absorption coefficient first increases, reaches a maximum of 1.0 g/cm³, and then decreases. In addition, by increasing the thickness of the filled fibers and maintaining the same density, the absorption coefficient increases and reaches a maximum thickness of 30 mm [22]. The results of the present study also showed a decrease in the absorption coefficient at frequencies of 3000 and 4000 Hz. And also, the adsorption coefficient increased with increasing adsorbent thickness. It seems that the increase in the adsorption coefficient is due to the higher damping surface and the more significant number of pores inside the material. In a study conducted by Ružickij et al. [23] To evaluate the sound

absorption properties of recycled tire textile fiber waste, increasing the thickness of rock wool adsorbent at low frequencies increased the absorption coefficient, which was in line with the results of the present study.

Forouharmajd et al. (2015) [24] explored the effect of applying a central axis dissipative silencer on noise reduction in the air inlet canal of a centrifuge blower fan. They observed that increasing the absorber thickness would yield better results regarding sound pressure level reduction. Similarly, in the current study, the rise of absorber thickness would lead to improved noise absorption (Figures 10 and 11).

Seddeq [14] examined the impact of physical features of materials, such as fiber type, size, thickness, density, and porosity, on noise absorption behavior. The results indicated a significant association between noise absorption coefficient and absorber thickness. Findings also showed that placing a space between the absorber and the installment area positively impacted the absorption rate. Likewise, in the current study, the presence of an air layer behind the absorber led to an improved noise absorption rate in low frequencies (Figures 10 and 11).

Zhang et al. [12] argued that since waves are longer in low frequencies, it is more challenging to absorb noise in such frequencies. To reduce noise in low frequencies, thicker absorbers should take longer for noise waves to travel through the acoustic material and be transformed into heat. Similarly, in the present study, increasing the thickness of rock wool improved the absorption rate in low frequencies (Figures 10 and 11).

Yousefi et al. (2014) [13] explored the impact of dissipative silencers on reducing noise in low frequencies of Iranian axial fans. To this end, they examined the effect of absorber thickness and density on sound pressure level reduction using MATLAB. The researchers did not observe any significant noise reduction upon increasing the absorber's thickness
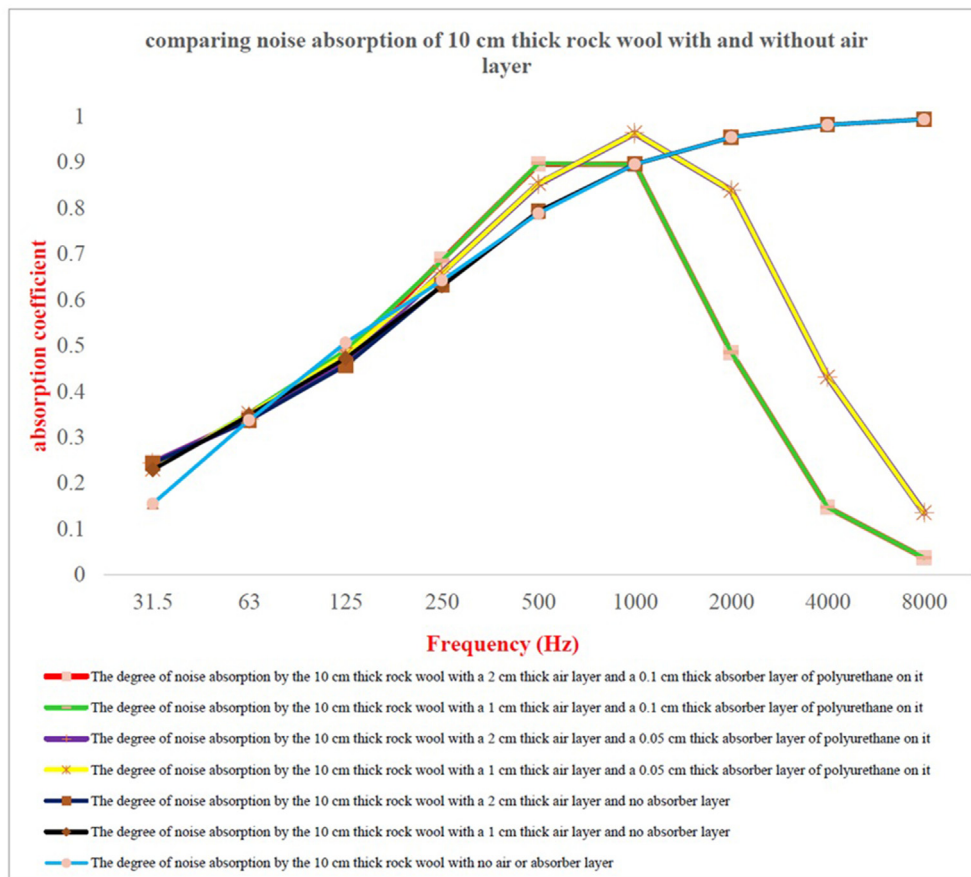
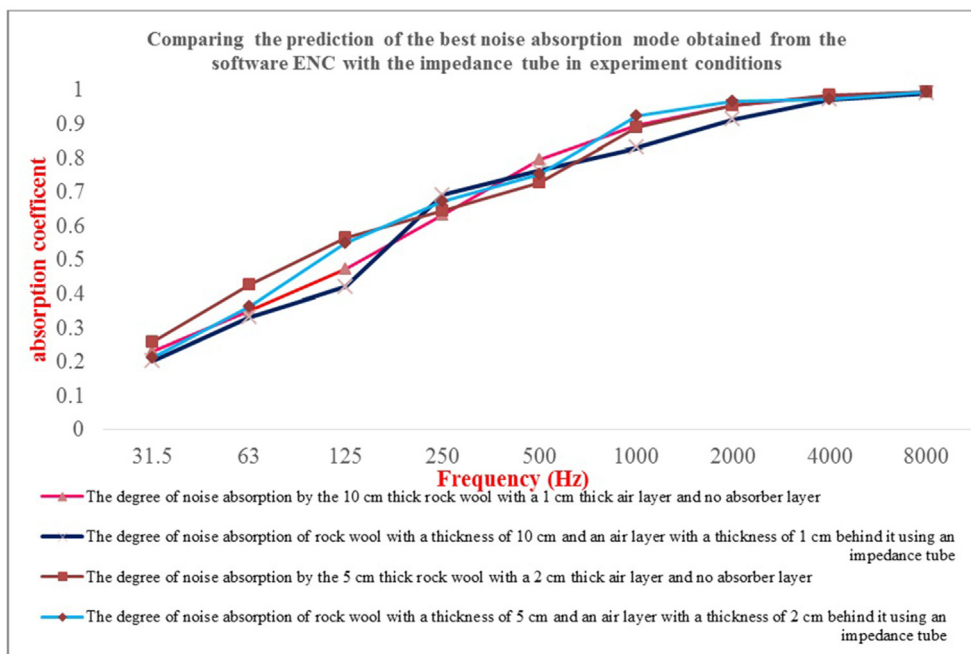**Figure 11.** Comparing the noise absorption of 5 cm thick rock wool.



**Figure 12.** Comparing the prediction of the best noise absorption mode obtained from the software ENC with the impedance tube in experiment conditions.

(i.e., mineral wool). This finding conflicts with the results obtained in the current study because, in our study, it was found that increasing the thickness of rock wool adsorbent improves sound absorption (Figures 10 and 11).

Forouharmajd et al. (2015) [25] aimed to examine the impact of optimizing the noise control process of a polystyrene silencer on the sound insertion loss index of a noise source as an enclosure in a laboratory. The presence of a 5 cm thick ionolite silencer with no porosities at

most reduced 34.5 dB of the noise at the frequency of 500 Hz. In contrast, increasing the ionolite thickness to 7 cm and inserting a hole with a 2 cm diameter led to more noise reduction in the frequencies of 250, 500, 1000, and 2000 Hz. According to the results obtained in the current study, increasing rock wool thickness to 10 cm led to more noise reduction in low frequencies. Thus, the results of our study partially conform to what was observed by Forouharmajd et al. because, in this study, with increasing the thickness of rock wool adsorbents, the sound absorption increases (Figure 4). In fact, Forouharmajd et al. observed that increasing the absorber's thickness would yield improved noise absorption, which aligns with the current findings (Figures 10 and 11).

Pleban (2017) [26] showed that increasing the thickness of rock wool and polyurethane would result in more noise absorption in high frequencies. Conversely, the results of our study demonstrated that the higher thickness of rock wool (without any air or absorber layer) did not lead to significant noise absorption changes in high frequencies. At the same time, it caused improved absorption in low frequencies. Moreover, we concluded that adding a polyurethane layer on rock wool slightly improved noise reduction in low frequencies but caused a significant decline in noise absorption in high frequencies. Thus, the results reported by Pleban conflict with our findings. In another study, Suhanek [27] showed improved noise absorption in high frequencies with the rise of rock wool thickness (Figures 10 and 11).

Williams et al. (2018) [11] sought to reduce low-frequency tonal noise in large ducts using a hybrid reactive-dissipative silencer. The results indicated that the dissipative silencer was more effective in the middle and high frequencies (which is in line with our findings). In contrast, the reactive silencer was more influential in low frequencies. As such, the researchers argued that a combination of reactive and dissipative silencers would yield improved levels of noise absorption in low and middle-range frequencies. In the current study, we observed that using 10 cm thick rock wool with no air or absorption layer did not significantly improve noise absorption in low frequencies. In contrast, a moderate to acceptable absorption range was observed for frequencies higher than 250 Hz. Our findings in this regard are in alignment with Williams' (Figures 10 and 11).

Denia et al. (2007) [15] examined the acoustic attenuation performance of perforated dissipative mufflers with empty inlet/outlet extensions. They found that applying the air layer results in a resonance that is one-fourth of the wavelength. Thus, the muffler functioning improves in low to middle range frequency, which agrees with our study's results. Because in this study, it was found that the addition of an air layer improves sound absorption for low to medium frequencies (Figures 10 and 11).

In specialized software, when performing calculations, there is a possibility of the existence of some degrees of freedom when changing the input parameters, which can lead to differences in the output results of the software with the results of experimental studies. For example, in a study by Kepekci et al., for a series of aeroacoustics investigations, a computational fluid dynamics software was used, and there was little difference between the outputs of the software and experimental studies [28]. However, in this study, the change in conditions (absorber thickness and frequencies) and different types of absorbent materials, as well as the change in the thickness of the air layer behind the absorber, have been evaluated and their effect on changing the results has been given. that our results in real conditions supported the findings of the ENC software. The results were completely consistent with the results of the study of Bhargava et al. [29].

## 5. Conclusion

The results of the present study showed that suitable and optimal conditions of sound absorption could be achieved by using conditions such as ENC software, correct design, use of suitable absorbers, changes in the physical parameters of the absorber, and the use of combined absorbers, The degree of the influence of these parameters on sound pressure level reduction is not the same. By detecting the best condition under which these factors exercise their optimal influence, various silencers with different efficiencies can be developed. One of the significant achievements of this study was the acceptable absorption rate registered for very low frequencies. The results of this study showed that due to the correlation between the data of ENC software and the impedance tube device, this software could be used more quickly and accurately to measure the amount of sound absorption in different conditions.

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