TEHRAN UNIVERSITY OF MEDICAL SCIENCES
IJOH INTERNATIONAL JOURNAL OF OCCUPATIONAL HYGIENE
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eISSN: 2008-5435
IRANIAN OCCUPATIONAL HEALTH ASSOCIATION IOHA

REVIEW ARTICLE

Performance of Noise Absorbers: A Systematic Review of Criteria for Low- to Mid-frequency Noise Absorbers

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Received 2023-05-13; Revised 2023-07-11; Accepted 2023-07-27

This paper is available on-line at http://ijoh.tums.ac.ir

ABSTRACT

Background: Absorption of low- to mid-frequency (LMF) noise has been challenging because of the inherently poor dissipation of classical noise-absorbing materials. For decades, the effective absorption of LMF noise has been an important topic and has attracted considerable interest from scientists in physics and engineering circles.

Method: This systematic review was conducted to assess the performance of LMF noise absorbers while considering influencing factors. Literature databases, including Scopus, Web of Science, IEEE, and Science Direct, were searched. In addition to the bibliographic sources, key publications and journal databases were searched from 2000 to 2022. Twenty studies were selected on the basis of the inclusion criteria. The data from the papers were analyzed via plot digitizer software.

Results: The results indicated that, with the exception of two factors resistivity and inner diameter the other factors positively affected the performance of low- to mid-frequency (between 40 and 1000 Hz) noise absorbers. With an increase in the number of layers, the absorption coefficient decreased by 0.06. In addition, increasing the surface porosity and thickness significantly increased the absorption coefficient at low to mid frequencies (0.16). By increasing the fiber gap, the absorption coefficient increased significantly by 0.06.

Conclusion: Among the various factors, the porosity, thickness, air gap, fiber gap, perforated plate, and mass had the most significant effects on the performance of the noise absorbers.

KEYWORDS: *Noise absorber, Criteria, Porosity, Thickness, Air gap, Perforated plate*

INTRODUCTION

The propagation of noise is a considerable engineering problem, for which numerous efforts have been made to solve it [1]. Noise pollution, which is caused by urbanization and industrial growth, has become a growing concern in the construction and automotive industries [2]. Globally, there are many studies on the health impacts of occupational and environmental exposure to noise. However, there are still few studies that focus exclusively on the health

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effects and discomfort caused by low- to mid-frequency noise [3]. One of the main reasons for this problem is that the human auditory system has low sensitivity to these frequencies [4]. On the other hand, noise with low to mid frequencies has very typical characteristics and causes greater annoyance and hearing loss [5–7]. Many studies have shown that low- to mid-frequency (LMF) noise is a strong stressor [4, 8, 9]. The most frequently mentioned impacts on human health are emotional and cognitive effects [10–12], cardiovascular diseases [13, 14], and sleep disorders [15, 16]. In addition, a large number of studies claim that low- to mid-frequency noise interferes with job performance [2].

A fundamental and important approach to reducing environmental and industrial noise is the use of sound absorbers [17]. With the industrialization of the world, noise control has become a public challenge of increasing urgency. Owing to the importance of noise reduction, recent research has been directed extensively toward noise absorbers [18]. Sound waves, which are a type of mechanical wave, require a material medium to propagate. During noise transmission, energy loss occurs, resulting in a continuous reduction in noise intensity, which is utilized in noise absorbers [18, 19].

LMF noise waves are generated by different types of equipment, such as low-resonance tools for rotating machinery, construction vibrators, fan noise, and transport equipment. Numerous studies have shown that LMF noise not only has numerous physical and psychological effects but also reduces the accuracy and stability of precision instruments and devices. The penetration depth of LMF noise is very large, and owing to the principle of causality, it is very difficult to control through traditional noise-absorbing materials in a confined space [20–24]. LMF noise is a commonly occurring phenomenon inside buildings and industries that is infrequently addressed [25], and for a long time, it has been treated as an environmental pollutant, mainly because of its high penetrating power [26]. Since the wavelength of LMF noise is too long, noise absorption in this frequency range is a challenging problem for engineers [27].

LMF noise is located in a powerful range of frequencies that undergo less reduction due to the presence of walls and structures. Furthermore, while it can mask higher frequencies, that masking is negligible. LMF noise is capable of traveling over very long distances, but while doing so, it undergoes some energy loss due to attenuation caused by the Earth and atmospheric effects. Hearing protection devices also have little effect on these frequency ranges [28]. It can also cause resonance in the human body, which may result in adverse mental and physiological effects [25].

Several articles have investigated the quality of LMF absorbers. Zent and John (2007) stated that there is no single material that delivers the best performance [29]. The porosity of perforated panels, together with the density of the material, may considerably affect the acoustic impedance and the absorption coefficient of noise [30]. To improve the acoustical properties of the absorbers, it is advisable to use perforated plates in the panels [30].

The absorption of these frequencies is more difficult, and this presents a specific problem for some industries. When absorption at lower frequencies is desired, thickness and weight are limited. The most common issue in noise absorption within the LMF range is the wide variation in impedance characteristics at these frequencies [31]. Notably, different factors can influence the performance of noise absorbers, such as fiber diameter (in fiber absorbers), porosity, thickness, resistance to flow, and density [32]. For example, the finer the diameter of a fiber, along with its resistance to airflow, density, and thickness, the greater the increase in noise absorption [31].

Changru Chen et al. (2017) noted that many studies from 1956 to the present have shown that prevalent noise-absorbing materials have a low ability for absorption in the low- to mid-frequency range [33]. Many attempts have been made to overcome this defect, including the application of different porous materials, multilayering, enhancement of the noise absorption path, and thin-film metamaterials. Nevertheless, the performance of the absorbers has improved only to some extent, and the problem has remained. Currently, because of exposure to high noise levels, the need for noise absorbents to attenuate noise through the development and reformation of materials is highly demanding [34].

According to the literature, the attenuation of LMF noise by absorbers has been reported to be controversial [35, 36]. Attenuation of LMF noise, which is more common in industrial environments, is more difficult than absorbing higher-frequency noise, while in most industrial and environmental environments, absorbing noise at lower frequencies is desirable [4, 7, 37]. Therefore, influencing factors such as thickness, weight,

Table 1. Key search words

Performance of absorbers	Design optimization, noise absorption coefficient, absorption coefficient, improvement, enhancing factors, performance improving factors, acoustic absorption, acoustic performance, sound pressure, Sound attenuation
Effective factors	sound properties, experimental analysis, perforated panel, acoustical characteristic, low frequency noise absorbers, vibro acoustic absorbers, sound properties, acoustical characteristic, composite noise absorption structure, effective factors, multilayer, impedance wavenumber, low frequency noise absorbers, porous materials acoustic model, perforated plates, composite panels, micro perforated panels, impedance tube
The frequency domain	>1600 Hz (Less than 1600 Hz)
Time period	January 2000– December 2022

flow resistance, porosity, and so on, with different settings, can be used to achieve the desired results. Owing to the limitations of LMF noise absorber studies, this study aimed to define a conceptual framework for the optimal absorption of low- to mid-frequency noise.

METHODS AND MATERIALS

Data sources and search

Scopus, Web of Science, IEEE, and ScienceDirect were searched as major databases for related studies published between January 1, 2000, and December 29, 2022. A broad selection of keywords related to the performance of LMF absorbers was used, which are presented in Table 1. In addition, review articles in this area were also assessed. *The Journal of the Acoustical Society of America*, *Low-Frequency Noise and Vibration*, and *Journal of Low Frequency Noise, Vibration and Active Control* were also searched. All of the keywords presented in Table 1 were searched with quotation marks and the “AND” operator.

Inclusion/exclusion criteria

The following inclusion/exclusion criteria were applied:

I. Performance factors: Only noise absorption related to the low to mid frequencies, not transmission loss, was considered.

II. Method of study design: Both experimental and validated models were assessed.

III. Noise-attenuation factors: Only noise absorbers included within the frequency range were considered. The noise barriers were not weighed.

IV. Study criterion: only peer-reviewed papers (not conference proceedings, reanalysis of outdated data, or reviews) were considered.

Procedure for assessment: the search in databases, evaluation of the papers, and their assessment, with inclusion and exclusion criteria, were carried out as follows:

1) In the first stage, the titles and abstracts of the articles that were extracted at the search stage were filtered on the basis of the relevance of the topic.

2) The hard copies of the articles that were relevant to the subject, with the use of preestablished criteria, were assessed.

3) The data were extracted from the papers.

4) Quality assessment of the articles was performed separately by the first and second authors via a checklist, and their cutoff score was 60% or higher.

5) The analysis was independently performed by the second author.

The following data were summarized for each eligible study: reference and country, study design, performance assessment of absorbers, different types of variables that impact LMF noise absorption, and the frequency of noise.

Data extraction

All of the graphs in the papers were analyzed with a plot digitizer, and they were converted to numerical data. Low- to mid-frequency ranges from 40–1000 Hz and 10 relevant variables with noise absorption coefficients were studied.

Statistical analyses

After the data were extracted and a qualitative evaluation of the articles was performed, the selected articles were screened using linear regression. Linear regression was used to investigate the effect of each structural factor on the performance of the LMF noise absorber. For this purpose, a univariate linear regression was run for each factor.

RESULTS

Fig. 1 shows the literature search process. In total, 1125 citations were examined, and 20 articles were selected on the basis of the inclusion and exclusion criteria.

A summary of the reviewed articles is shown in Figure 2 and Table 2. The results show that many factors

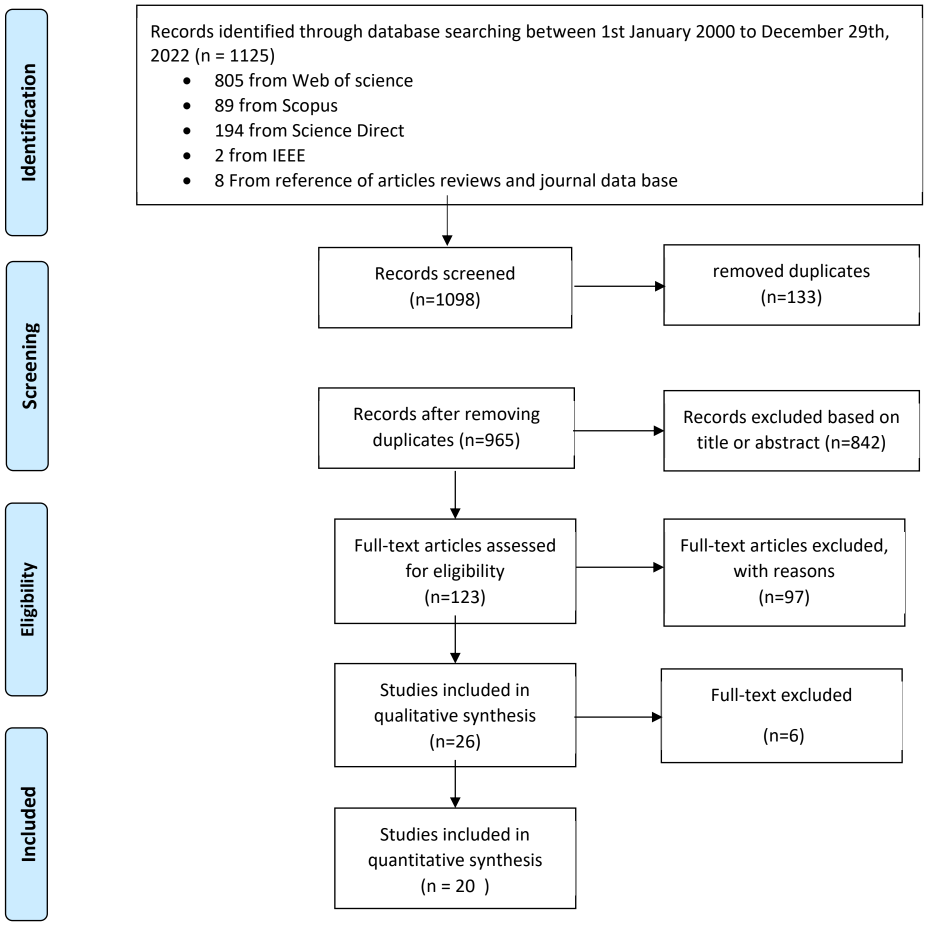

Figure 1. Diagram of the study selection process

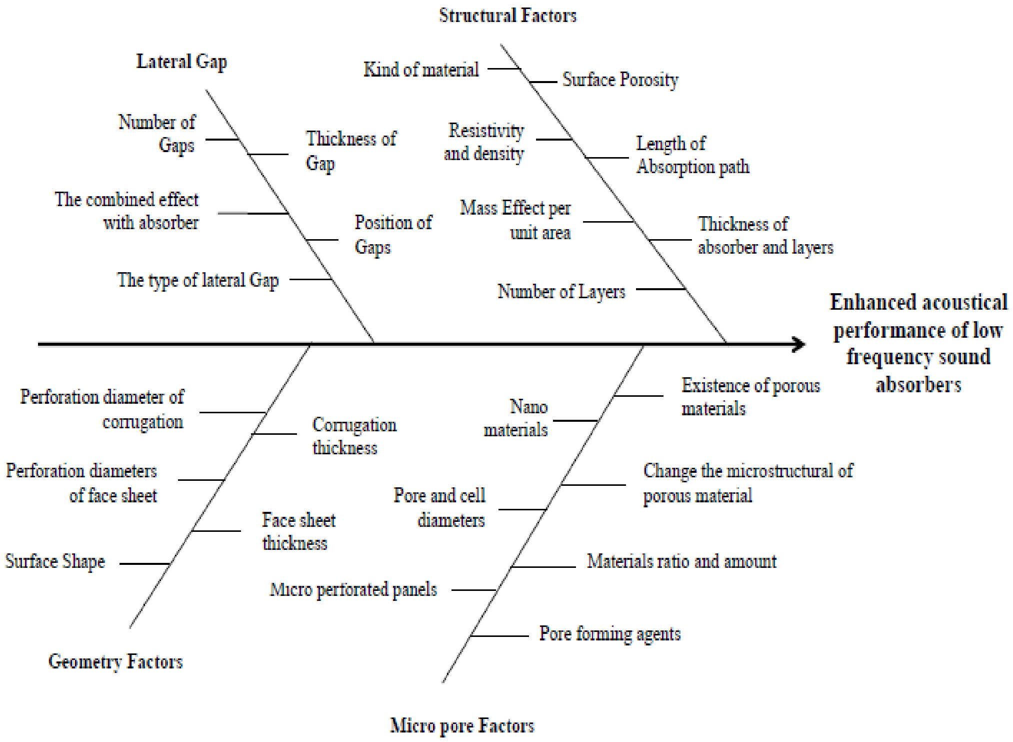

Figure 2. Causes and effects of influencing factors on absorption (Ishikawa diagram)

Table 2. Observational studies on the Association between the effective factors and performance of low-frequency noise absorbers.

Study	Year	Methods	Frequency domain (Hz)	Variables	Findings
Low-Frequency Sound Absorption of Organic Hybrid Material[38]	2005	Experimental	50-1600	Heat treatment	By heat treatment, it could be made to control the sound absorption frequency of organic hybrid materials.
A low-frequency sound absorbing material with subwavelength thickness[33]	2017	1. Numerical simulation: COMSOL 2. Analytical model 3. Experimental	50-150 & 400-1200	Axially coupled tubes in series	By carefully designing the geometric parameters of the coupled tubes, they can overlap the absorption coefficient curves of each individual tube and are therefore able to broaden the frequency bandwidth within which the absorption coefficient is larger than a designed value.
Design of multilayered porous fibrous metals for optimal sound absorption in the low frequency range[39]	2016	1. Phenomenological Model 2. Experimental	0-500	Porosity, thickness, fiber gap	A new fibrous layout with a given porosity of multilayered fibrous metals is suggested. The performance of the optimal multilayered fibrous material is higher than the single-layered fibrous material, and a significant effect of the fibrous material on sound absorption is found due to the surface porosity of the multilayered fibrous material.
Analytical coupled vibroacoustic modeling of membrane-type acoustic metamaterials: plate model[40]	2014	1. Theoretical plate model 2. Numerical simulation: COMSOL	100-1000	Microstructure effects, the depth, thickness, and loss factor	As the mass of MAMs (Membrane-type acoustic metamaterials) increases, resonant frequencies increase in the low frequency range, which can produce higher peaks of sound absorption and ultimately, it broadens the range of sound absorption.
Utilization of coir fiber in multilayer acoustic absorption panel[41]	2010	1. PP modeling approaches 2. Experimental	>2000	Perforated plate (PP) In front of the fiber layer or between fiber–air gap layers.	PP may increase the absorption of coir fiber at low frequencies, but it will reduce the performance on midrange frequencies. The advantage of using PP was that it greatly reduced the thickness of the air gap in similar absorption performance conditions.
Sound absorption performance of layered microperforated and poro-elastic materials[42]	2013	1. Maa's flow resistance model 2. Rigid model 3. Experimental: impedance tube	50- 1600	Hole diameter, hole depth (panel thickness), Mass/area, Porosity	The peak absorption frequency changes to the higher frequency range as d/t rises from 0.5 to 1.5. By increasing the diameter of the hole, the peak absorption shifted to the lower frequencies. As the ratio of hole diameter to hole thickness is lowered, the absorption shifts to lower frequencies.
Enhancing the low-frequency sound absorption of a perforated panel by parallel-arranged extended tubes[43]	2016	Theoretical analysis	<500	The thickness of the clapboard on the sound absorption of the four parallel-arranged	The results showed that these absorbers showed better responses than conventional ones in the low frequency range. Consequently, the method described in the paper is useful for the design of a sound absorber at low frequencies. As a result, this method can be useful for designing LFN absorbers.
Dark acoustic metamaterials as super absorbers for low-frequency sound[44]	2012	1. COMSOL and laser measurement 2. Measurement: impedance tube	100-1000	The corresponding experimental data	As the flapping movements are at least radiational modes, the overall membrane energy density can be two or three times larger than the incident wave energy density at low frequencies.
Optimization of low-frequency sound absorption by cell size control and multiscale proacoustics modeling[45]	2017	Unit cell modeling proacoustics simulation method	<1200	Cell diameter Pore diameter Cell number density	The structural dimensions cell of irradiated foams were approximately 40% smaller than the nonirradiated ones. With this strategy, the cell modifies the size of the target range, even a small space for control of low-frequency was enough, and increasing density is not necessary to increase the fuel consumption of transport vehicles.

Table 2. Observational studies on the Association between the effective factors and performance of low-frequency noise absorbers.

Study	Year	Methods	Frequency domain (Hz)	Variables	Findings
Preparation and Low-Frequency Sound Absorption Properties of Silicate Composite Material[46]	2012	Experimental	125-2000	Pore-forming agent amount of water-cement ratio PMI Amount	By using poly methacrylic imide (PMI) and silicate powder foam, the absorption coefficient of low frequencies has increased. The absorption coefficient increased with water water-cement ratio of 0.55, and after that absorption decreased, and this water in the macropores reduces the absorption coefficient.
Improvement of sound absorption characteristics under low frequency for micro perforated panel absorbers using superaligned carbon nanotube arrays[47]	2014	The predicted and measured normal absorption	1500-6500	Diameter of the perforations, panel thickness depth of the cavity	In general, the performance of the microperforated panel (MPP) absorbers is decreased by SACNT arrays when the MPP panel surface is on the incident side. Thus, it can be concluded that the arrays can be used to increase the performance of the MPP low-frequency absorber's function.
Sound absorption properties of composite structure with activated carbon fiber felts[48]	2014	Experimental	80-6300	Position of activated carbon fiber felts, thickness, and air space	Perforated panels had a very good role in the sound absorption at 80-3500 Hz. Sound absorption properties of the composite at a thickness of 15.6 mm had similar traits to the porous materials at 80–6300 Hz frequencies. Sound absorption properties were improving with the increase in the distance of air space, toward the low frequencies at 80–650 Hz.
A hybrid acoustic metamaterial as Super absorber for broadband low-frequency sound[49]	2017	1. COMSOL 2. Experimental	<1500	Different H-C hybrid honeycomb-corrugation hybrid (PHCH)	A new class of sound absorber called a hybrid acoustic metamaterial is proposed, which has excellent mechanical stiffness/strength, and has perfect as well as broadband low-frequency sound absorption. To gain superior broadband low-frequency sound absorption, perforations are made on both the top face sheet and corrugation, forming a perforated honeycomb-corrugation hybrid (PHCH).
Enhancing low-frequency sound absorption of microperforated panel absorbers by using mechanical impedance plates[50]	2015	1. Transfer matrix 2. Experimental	<1600	Single and double leaf MPP	The experimental results and theoretical calculations were in good agreement. The composite structure comprises combining the mechanical resonance and sound absorption mechanisms of cavity resonance. The enhanced low-frequency sound occurred without the need to increase the total thickness of the structure.
Noise Control Using Coconut Coir Fiber Sound Absorber with Porous Layer Backing and Perforated Panel[30]	2010	Experimental	50-4700	Coconut coir fiber without a porous layer	At low frequency, the performance has significantly increased. Woven Cotton Cloth (WCC) has more flow resistance than coconut coir fibers. The results of the experiments show that they have good acoustic properties at low frequencies and can be a good replacement for a commercially based product.
Sound propagation in and low-frequency noise absorption by helium-filled porous material[51]	2009	Experimental	<1900	Massless membrane-absorber	This study indicates that by filling a low-density gas, such as helium, in the porous materials, the effective range of sound absorption shifts to lower frequencies. The helium-filled porous materials, compared with the air-filled ones, had less impedance characteristic; as a result, it was more feasible and had good impedance matching of impedance and pure air at low frequencies. The experimental results showed that the proposed new absorber has excellent absorption (95.9%-99.9%) at low-frequency bands in the massless membrane sound absorber.
A tunable massless membrane material for perfect and low-frequency sound absorption [24]	2021	Experimental	<500		
	2019	Simulation : FE Model	180 – 550		

Table 2. Observational studies on the Association between the effective factors and performance of low-frequency noise absorbers.

Study	Year	Methods	Frequency domain (Hz)	Variables	Findings
Broadband low-frequency sound absorption by periodic metamaterial resonators embedded in a porous layer [25]	2018	1. Transfer matrix 2. Experimental	200-600	Thickness, rigid backing	At low frequencies, ranging from 180 Hz to 550 Hz, sound absorption was significantly elevated (>80%) while the thickness of the layer is only 1=10 of the relevant wavelength at 300 Hz.
Enhancing the low-frequency sound absorption of a microperforated panel absorbers by combining parallel mechanical impedance [26]	2020	Experimental	<500	Parallel mechanical impedance structure plane	The study showed that a composite structure can enhance the low-frequency sound absorption effect of the MPP while the whole structure does not occupy too much space. The experimental results were in good agreement with the theoretical results.
A double porosity material for low-frequency sound Absorption [27]				A double porosity material (DPM)	The research shows that the designed DPM enhances the sound absorption at low frequencies.

can affect the performance of the absorbers. These effective factors can be categorized into subgroups that are individually identified. Among these factors, the structural factors and lateral gap subgroups were reviewed in the articles. The results of their statistical analyses are presented below.

Data synthesis: How does it influence the performance of LMF absorbers?

The effects of structural factors and the lateral gap on the performance of the LMF absorber are tabulated in Table 3. The results indicated that all the factors, except for resistivity and inner diameter, are positively associated with performance. In essence, increasing those positively associated factors results in increased absorber performance. However, the associations for factors such as temperature, air gap, and layer were not statistically significant. Conversely, both resistivity and inner diameter were negatively associated with performance. Additionally, the association between resistivity and performance was statistically significant.

DISCUSSION

In this study, articles published between 2000 and 2022 on low- to mid-frequency noise absorbers were systematically reviewed. The role of influencing factors, including the lateral gap and structural factors, in the absorption of LMF noise was identified. Additionally, a univariate linear regression was carried out to estimate the correlation of these factors with the performance of the noise absorbers. The results revealed some associations between these factors and the noise absorption coefficients, as shown in Table 3. Among the various factors, porosity, thickness, air gap, fiber gap, perforated plate, mass, and resistivity had the most significant effects on the performance of the noise absorbers (p-value < 0.001).

With increasing unit thickness, the noise absorption coefficient increases to 0.02 [31]. This finding indicates that greater penetration of noise waves occurs in thicker absorbers because the characteristic impedance might be reduced. However, a quarter of a wavelength provides good thickness for sufficient noise absorption, but in low- to mid-frequency noise, it poses a significant problem [51].

If the thickness of the absorber increases along with the air layer, the increase in the absorption coefficient is not significant. However, increasing the air layer alone significantly increased the absorption coefficient from 0.05 to 0.08, depending on the material used, which can vary [31]. Notably, in the case of a microperforated membrane, the increasing trend of the absorption

Table 3. Result of the analysis of the performance of the noise absorbers

Structural Factor	β coefficient	SE	P value	95% CI
Temperature	0.01	0.01	0.39	(-0.02 to 0.05)
PT_1	0.14	0.01	<0.001	(0.11 to 0.16)
PT_2	0.16	0.01	<0.001	(0.14 to 0.19)
Thickness	0.02	0.008	<0.001	(0.01 to 0.04)
Thickness + air gap	0.03	0.01	0.04	(0.00 to 0.06)
Air gap (AL. MPP)1	0.08	0.02	<0.001	(0.03 to 0.14)
Air gap (AL. MPP)2	0.08	0.02	<0.001	(0.03 to 0.14)
Air gap (Plastic film)1	0.08	0.03	0.01	(0.01 to 0.14)
Air gap (Plastic film)2	0.07	0.02	<0.001	(0.02 to 0.13)
Air gap (MPM)	0.05	0.02	0.05	(-0.001 to 0.11)
Layer	0.06	0.04	0.18	(-0.03 to 0.16)
Fiber gap	0.06	0.01	<0.001	(0.03 to 0.09)
Perforation plate	0.08	0.02	<0.001	(0.03 to 0.13)
Mass effect	0.05	0.01	<0.001	(0.01 to 0.08)
Resistivity	-0.08	0.02	<0.001	(-0.13 to -0.03)
Inner diameter	-0.03	0.02	0.23	(-0.08 to 0.02)

N = 16 studies

PT: porosity, thickness

AL. MPP: Aluminum Micro perforated panel

MPM: Micro-Perforated Membrane

1: Simulation

2: Experimental

coefficient with increasing air layer is reversed, which may be attributed to the porosity of the surface, although this effect is not significant [52]. Porosity is an effective factor for noise control in low-frequency noise, even if there are no changes in the air thickness of the panel [31]. Compared with traditional ¼-wave materials, microperforated materials effectively increase low-frequency noise absorption [42]. Researchers have shown that increasing the thickness of the air gap improves low-frequency noise absorption, and the addition of more layers, such as perforated plates, enhances absorption without the use of a large air gap [41].

With increasing material resistance, the absorption coefficient decreases significantly by 0.08, and with increasing sample inner diameter, the absorption coefficient decreases by 0.03. Increasing the perforation of the plate significantly increases the absorption coefficient by 0.08. Higher and smaller macroporosities are the cause of higher absorption at low and high frequencies. It is believed that the design of porous materials has improved the role of absorption at low frequencies [41]. As the density of the material increases, the absorption coefficient increases significantly by as much as 0.05. Density affects the impedance of noise, as impedance reflects materials [35].

Disregarding thickness, with an increase in the number of layers, the absorption coefficient decreased by 0.06; however, this was not significant. Interestingly, increasing surface porosity and thickness significantly increased the absorption coefficient at low frequencies (0.16). By increasing the fiber gap, the absorption coefficient increased significantly by 0.06. Since lower surface porosity increases acoustic resistance, noise resistance plays an important role in LMF sound absorption. Although more acoustic energy can be eliminated with higher acoustic resistance in porous media, a greater percentage of the acoustic energy is reflected when the surface porosity is very low [39].

The porosity of acoustic materials is largely based on their intrinsic properties and plays an important role in sound propagation theories. This parameter is involved in describing the viscous coupling between the fluid and the structure. Porosity is the ratio of the volume occupied by the fluid phase to the total volume of the porous material. Porosity is also important as one of the parameters required in acoustic theory to describe porous materials [35, 37]. Thicker absorber materials produce better noise absorption coefficients; nevertheless, as the frequency increases, the absorption shifts to thinner materials. Thicker materials have better noise absorption in the LMF range. Standards have clarified that to obtain better performance, the thickness of the materials should be at least one-tenth of the wavelength for that frequency [35].

CONCLUSION

The purpose of this paper was to review the studies carried out on the performance of low- to mid-frequency noise absorbers based on articles published between 2000 and 2022. The data from the review of 20 papers, taken from the Scopus database and snowball search, were analyzed via plot digitizer software. In this systematic review, the materials' characteristics, referring to their test methods, were assessed for detecting the absorption coefficient. Among the various factors, porosity, thickness, air gap, fiber gap, perforated plate, and mass had the most significant effects on the performance of the noise absorbers. In fact, the results showed that, with the exception of two factors—resistivity and inner diameter—the other factors positively affected the performance of LMF noise absorbers, and with an increase in the number of layers, the absorption coefficient decreased. In addition, increasing the surface porosity and thickness significantly increases the absorption coefficient at low- to mid-frequencies; by increasing the fiber gap, the absorption coefficient also increases significantly. This paper may help address this problem and provide a simple synthesis of information in this area of study.

SUGGESTIONS FOR FUTURE RESEARCH DIRECTIONS

Future studies should review the application of advanced methods, from modeling to the design of noise absorbers, including finite element modeling. These review techniques can enhance overall acoustic performance and optimize configurations to maximize sound absorption efficiency.

LIMITATION

The main limitation of this literature review was the difficulty of achieving true comprehensiveness due to the vast amount of noise-related research.

ACKNOWLEDGMENTS

This article is based on a research project. The authors would like to thank Hormozgan University of Medical Sciences for their technical and financial support.

FUNDING

This article was financially supported by grant number 980291 from Hormozgan University of Medical Sciences.

CONFLICT OF INTEREST

The authors confirm that there are no conflicts of interest associated with this publication.

ETHICAL CONSIDERATION

The study was approved by the university ethics committee. The code of ethics is IR.HUMS.REC.1399.125

REFERENCES

1. Lee JK, Kwon SB, Kim YH, Lee PJ. Noise reduction of passive and active hybrid panels. Smart Mater Struct. 2002;11(6):940.
2. Araújo Alves J, Silva LT, Remoaldo PC. Low-frequency noise and its main effects on human health—A review of the literature between 2016 and 2019. Appl Sci. 2020;10(15):5205.
3. Caniato M, Bettarello F, Schmid C. Low frequency noise and disturbance assessment methods: A brief literature overview and a new proposal. Proc Meet Acoust. 2016;27:040003.
4. Howe B, Principal P. Low frequency noise and infrasound associated with wind turbine generator systems: a literature review. Ontario: Ministry of the Environment RFP; 2010.
5. Pawlaczyk-Łuszczyńska M, Dudarewicz A, Zaborowski K, Zamojska-Daniszewska M, Waszkowska M. Evaluation of annoyance from low frequency noise under laboratory conditions. Noise Health. 2010;12(48):166–81.
6. Alves JA, Silva LT, Remoaldo PC. Impacts of low frequency noise exposure on well-being: a case-study from Portugal. Noise Health. 2018;20(95):131–45.
7. Jafari MJ, Monazam MR, Kazempour M. Providing an optimal porous absorbent pattern to reduce mid to low-frequency sounds. J Environ Health Sci Eng. 2018;16:289–97.
8. Baliatsas C, van Kamp I, van Poll R, Yzermans J. Health effects from low-frequency noise and infrasound in the general population: Is it time to listen? A systematic review of observational studies. Sci Total Environ. 2016;557–558:163–9.
9. Shehap AM, Shawky HA, El-Basheer TM. Study and assessment of low frequency noise in occupational settings. Arch Acoust. 2016;41(1):151–60.
10. Silva LT, Alves JA, Remoaldo PC. A mobile environmental monitoring station for sustainable cities. Environ Econ Impact Sustain Dev. 2016;1:123.
11. Kazempour M, Monazam MR, Jafari MJ. The impact of low frequency noise on mental performance during math calculations. Presented at: 1st National Conference on Noise Pollution; 2011.
12. Jafari M, Kazempour M. Mental processing of human subjects with different individual characters exposed to low frequency noise. Int J Occup Hyg. 2013;5(2):64–70.
13. Babisch W. Traffic noise and cardiovascular disease: epidemiological review and synthesis. Noise Health. 2000;2(8):9–32.
14. Passchier-Vermeer W, Passchier WF. Noise exposure and public health. Environ Health Perspect. 2000;108(Suppl 1):123–31.
15. Ising H, Kruppa B. Health effects caused by noise: evidence in the literature from the past 25 years. Noise

Health. 2004;6(22):5–13.
16. Bluhm G, Nordling E, Berglind N. Road traffic noise and hypertension. Occup Environ Med. 2007;64(2):122–6.
17. Zanganeh J, Kundu S, Moghtaderi B. An innovative passive noise control technique for environmental protection: An experimental study in explosion noise attenuation. Sustainability. 2024;16(8):3201.
18. Chang L, Zhang Y, Wang Y, Li Y, Zhang X. Progress of low-frequency sound absorption research utilizing intelligent materials and acoustic metamaterials. Appl Sci. 2021;11(60):37784–800.
19. Banerjee A, Das R, Calius EPJ. Waves in structured mediums or metamaterials: a review. Arch Comput Methods Eng. 2019;26:1029–58.
20. Broner N. The effects of low frequency noise on people—a review. J Sound Vib. 1978;58(4):483–500.
21. Morrow CT. Noise control versus shock and vibration engineering. J Acoust Soc Am. 1974;55(4):695–9.
22. Carey WM, Wagstaff RA. Low-frequency noise fields. J Acoust Soc Am. 1986;80(5):1523–6.
23. Jafari M, Monazzam MR, Nezafat A, Azari MR. The influences of low frequency noise on mental performance. Iran Occup Health. 2008;18(63):55–65.
24. Jafari M, Kazempour MJ. Mental processing of human subjects with different individual characters exposed to low frequency noise. Int J Occup Hyg. 2013;5(2):64–70.
25. Berglund B, Hassmén P, Job RS. Sources and effects of low-frequency noise. J Acoust Soc Am. 1996;99(5):2985–3002.
26. Yang Z, Lee Y, Wang Y, Lee S. Acoustic metamaterial panels for sound attenuation in the 50–1000 Hz regime. Appl Phys Lett. 2010;96(4):041906.
27. Allard JF, Atalla N. Propagation of sound in porous media: modelling sound absorbing materials. 2nd ed. Chichester: John Wiley & Sons; 2009.
28. Patra H, Roup CM, Feth LL. Masking of low-frequency signals by high-frequency, high-level narrow bands of noise. J Acoust Soc Am. 2011;129(2):876–87.
29. Zent A, Long JT. Automotive sound absorbing material survey results. SAE Tech Pap. 2007.
30. Rozli Z, Zulkarnain Z. Noise control using coconut coir fiber sound absorber with porous layer backing and perforated panel. Am J Appl Sci. 2010;7(2):260–4.
31. Jafari MJ, Monazzam MR, Kazempour M. Providing an optimal porous absorbent pattern to reduce mid to low-frequency sounds. J Environ Health Sci Eng. 2018;16:289–97.
32. Zhang Y, Cheng LJ. Ultra-thin and broadband low-frequency underwater acoustic meta-absorber. Int J Mech Sci. 2021;210:106732.
33. Chen C, Zhang X, Wang Y, Liu Y. A low-frequency sound absorbing material with subwavelength thickness. Appl Phys Lett. 2017;110(22):221903.
34. Puranik PR, Rana PP, Puranik RRP. Nonwoven acoustic textiles – a review. Int J Adv Res Eng Technol. 2014;5(3):8.
35. Amares S, Rahman NA, Zulkarnain Z, et al. A review: characteristics of noise absorption material. J Phys Conf Ser. 2017;908:012005.
36. Puranik PR, Rana PP, Puranik RRP. Nonwoven acoustic textiles–a review. J Adv Res Sci Eng Technol. 2014;5(8).
37. Scandurra G, D'Antonio E, Ianniello C, et al. A review of design approaches for the implementation of low-frequency noise measurement systems. Rev Sci Instrum. 2022;93(11):115001.
38. Akasaka S, Yamamoto T, Kuroda M, et al. Low-frequency sound absorption of organic hybrid comprised of chlorinated polyethylene and N,N′-dicyclohexyl-2-benzothiazolyl sulfenamide. J Appl Polym Sci. 2006;99(6):2878–84.
39. Chen W, Zhang X, Wang Y, et al. Design of multi-layered porous fibrous metals for optimal sound absorption in the low frequency range. Theor Appl Mech Lett. 2016;6(1):42–8.
40. Chen Y, Liu Y, Hu G, Huang G. Analytical coupled vibroacoustic modeling of membrane-type acoustic metamaterials: Plate model. J Acoust Soc Am. 2014;136(6):2926–34.
41. Fouladi MH, Ayub M, Nor MJM. Utilization of coir fiber in multilayer acoustic absorption panel. Appl Acoust. 2010;71(3):241–9.
42. Kim JW, Mendoza JM. Sound absorption performance of layered micro-perforated and poro-elastic materials. Noise Control Eng J. 2013;61(1):100–13.
43. Li D, Chang D, Liu B. Enhancing the low frequency sound absorption of a perforated panel by parallel-arranged extended tubes. Appl Acoust. 2016;102:126–32.
44. Mei J, Ma G, Yang M, Yang Z, Wen W, Sheng P. Dark acoustic metamaterials as super absorbers for low-frequency sound. Nat Commun. 2012;3:756.
45. Park JH, Lee JH, Kim Y, Lee PJ. Optimization of low frequency sound absorption by cell size control and multiscale poroacoustics modeling. J Sound Vib. 2017;397:17–30.
46. Peng LG, Zhang Y, Wang Y, Li J. Preparation and low frequency sound absorption properties of silicate composite material. Adv Mater Res. 2012;482–484:1133–6.
47. Qian Y, Wang Y, Zhang X, Liu Y. Improvement of sound absorption characteristics under low frequency for micro-perforated panel absorbers using super-aligned carbon nanotube arrays. Appl Acoust. 2014;82:23–7.
48. Shen Y, Jiang G. Sound absorption properties of composite structure with activated carbon fiber felts. J Text Inst. 2014;105(10):1100–7.
49. Tang Y, Yang M, Dai H, Naify CJ, Cheng Y, Jing Y. Hybrid acoustic metamaterial as super absorber for broadband low-frequency sound. Sci Rep. 2017;7:43340.
50. Zhao X, Fan X. Enhancing low frequency sound absorption of micro-perforated panel absorbers by using mechanical impedance plates. Appl Acoust. 2015;88:123–8.
51. Choy Y, Huang L, Wang C. Sound propagation in and low frequency noise absorption by helium-filled porous material. J Acoust Soc Am. 2009;126(6):3008–19.
52. Mihan A, Jafari MJ, Monazzam MR, Kazempour M, Ghanbari R. Social accountability in undergraduate medical education: a narrative review. Educ Health (Abingdon). 2022;35(1):3–8.