

Acoustics Application and Properties of Nonwovens: A Review**Nitesh Kumar Jangir, Harshvardhan Saraswat****Department of Textile Technology****MLV Textile and Engineering College****Bhilwara****(Received:10June2021/Revised:20June2021/Accepted:1July2021/Published:6July2021)****Abstract**

Acoustics, as the science of sound, spans a wide array of applications, from noise control and architectural acoustics to medical imaging and environmental sustainability. Nonwoven textiles, due to their lightweight and eco-friendly properties, are gaining attention for acoustic applications. This paper explores the evolution of acoustics, delving into fundamental concepts such as sound characteristics, measurement techniques, and advanced tools like microphones. The focus shifts to nonwoven materials, highlighting their potential in sound absorption and insulation, particularly through natural fiber blends such as cotton, kapok, and milkweed. These materials are discussed in terms of their ability to enhance sound reduction and thermal insulation properties. The review also examines experimental techniques like ASTM standards for evaluating sound absorption, alongside theoretical models that predict acoustic performance. Through a synthesis of recent studies and advancements, this paper underscores the importance of nonwovens as sustainable and efficient acoustic solutions across industries, paving the way for future research and applications.

Key Words: Acoustic Behavior, Needlepunched Structures, Sound Absorbency, Noise Level

1. Introduction

Acoustics, as defined, encompasses the science of sound production, control, transmission, reception, and its manifold effects. Though often misconceived as being limited to music and architecture, acoustics is a truly multidisciplinary field spanning a wide spectrum of applications. It involves not only the study of musical instruments and architectural acoustics but also delves into noise control, submarine navigation via SONAR technology, medical imaging through ultrasounds, innovative refrigeration using thermoacoustic methods, seismology for earthquake analysis, bioacoustics exploring sound in the natural world, and electroacoustic communication systems. R. Bruce Lindsey's [1] 'Wheel of Acoustics' illustrates this expansive nature by categorizing acoustics into four overarching domains: Earth Sciences, Engineering, Life Sciences, and the Arts, with each domain leading to a plethora of specialized fields within the realm of acoustics.

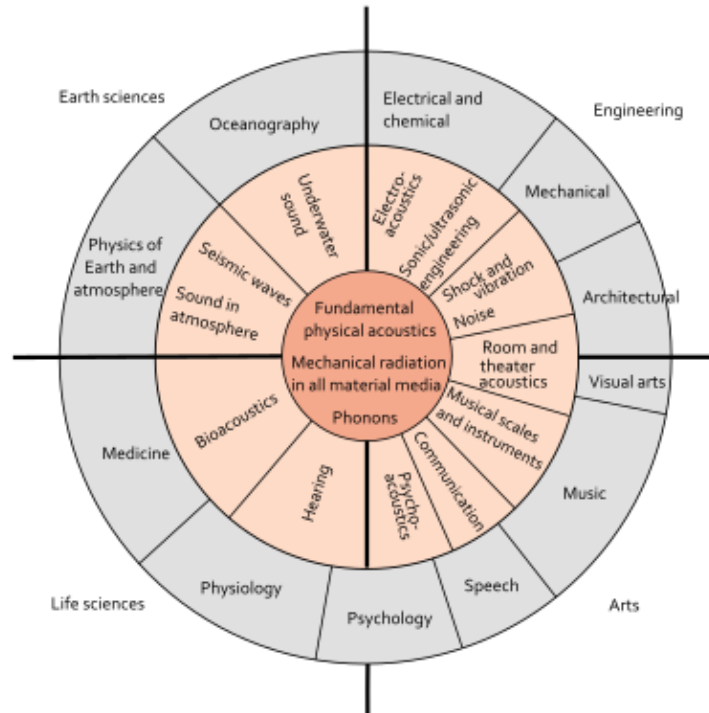


Fig. 1 Lindsay's Wheel of Acoustics, which shows fields within acoustics [1]

1.1 History of Acoustics [2-8]

In just over a century, acoustics has transformed remarkably, evolving from an art form into a rigorous science. In the 1920s, engineers primarily relied on their auditory senses for measurements, using controlled noise sources like whistles and gongs. However, major advancements such as the invention of triode-vacuum-tube circuits in 1907 and the onset of radio broadcasting in 1920 paved the way for precise measuring instruments, turning acoustics into a precision engineering field. During World War II, research in acoustics intensified, particularly in England, Germany, France, and the United States, to address critical needs such as submarine detection and reliable speech communication amidst noisy environments. Today, as of 2021, acoustics has expanded far beyond a niche discipline, becoming an integral part of daily life, influencing aspects ranging from residential and workplace comfort to home entertainment, aviation noise control, and industrial applications. This transformative journey has been marked by the contributions of prominent figures like Lord Rayleigh, W. C. Sabine, and Harvey Fletcher, along with the efforts of numerous research centers and institutions. Acoustics has shifted from serving mainly the telephone industry and military to becoming a central concern for individuals and industries worldwide. International initiatives are advocating for regulations to ensure quiet living environments, architects are increasingly collaborating with acoustical engineers, acoustic instruments are

commonplace in manufacturing, and high-fidelity sound systems are popular in homes. This comprehensive book, authored in 2023, stands as a testament to the rich history and crucial role of acoustics in our technologically advanced, noise-conscious world.

2 What is sound?

Sound is a form of energy that travels as waves through a medium, usually air, but it can also propagate through water or solids. These waves are made up of compressions and rarefactions, which create regions of high and low pressure as they move. When an object vibrates or generates a disturbance, it causes the particles in the surrounding medium to vibrate, creating a chain reaction of particle vibrations. This movement is transmitted through the medium, resulting in what we perceive as sound

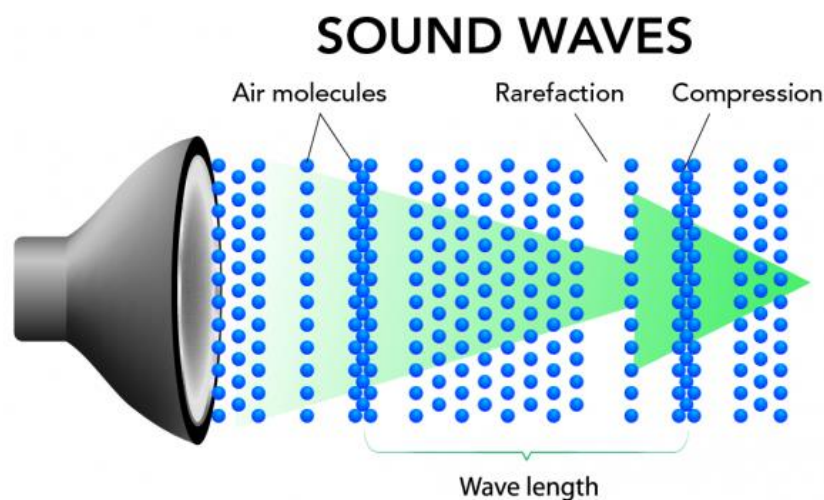


Fig. 2 Propagation of sound wave [1]

2.1 Characteristics of Sound Wave

Sound is similar to the ripples that form when you throw a stone into a pond. It travels in a unique way, with particles in the air or other materials moving back and forth as the sound energy passes through. This movement creates areas of higher pressure (called compressions) and lower pressure (called rarefactions). These changes in pressure move through the medium, allowing sound to travel from one place to another. This process is what enables us to hear and understand the sounds around us.

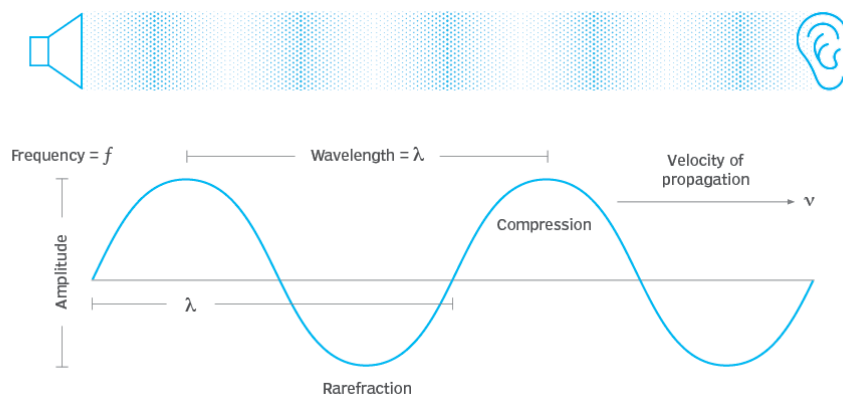


Fig 3 Characteristics Of Sound Wave

2.1.1 Wavelength

Wavelength (λ) is the distance between two consecutive points in a repeating wave pattern, such as from one crest (highest point) to the next crest in a water wave or from one compression to the next in a sound wave. It's like measuring the distance from one peak to the next on a roller coaster. Wavelength tells us the length of one complete cycle of the wave. It is inversely related to the wave's frequency—waves with shorter wavelengths have higher frequencies, while longer wavelengths correspond to lower frequencies.

2.1.2 Amplitude

Amplitude is the magnitude of the maximum disturbance in a sound wave. It represents the energy of the wave—higher amplitudes indicate higher energy. In sound waves, amplitude is related to the perceived loudness; larger amplitudes result in louder sounds.

2.1.3 Frequency

Frequency (ν) is the number of compressions and rarefactions (one complete cycle) that occur per unit of time in a sound wave. The unit of frequency is Hertz (Hz). The relationship between frequency and time period (T) is given by:

$$\nu = \frac{1}{T}$$

Where T represents the time taken to complete one cycle, also known as the time period.

2.1.4 Speed

The speed of sound (c) is the rate at which sound waves travel through a medium. The speed can be expressed using the relationship:

$$c = \frac{\lambda}{T} = \lambda \nu$$

Where:

c : Speed of sound

λ : Wavelength

T: Time period

v: Frequency

2.2 Some important Phrases In Acoustics

Sound Pressure (p): It represents the force exerted by a vibrating object divided by the area over which the force is applied, measured in Pascals (Pa).

Sound Intensity (I): This measures the power of sound and is calculated as the square of sound pressure divided by the product of the density of the sound-transmitting medium and the speed of sound.

Decibel (dB): It's a unit used to express the relative intensity or pressure of sound compared to a reference intensity or pressure. Commonly used to measure sound pressure levels (dB SPL).

Hertz (Hz): It measures the frequency of vibratory motion, with one Hertz representing one cycle per second.

Phase (angular degrees): It quantifies where a specific point in a sound wave is within a cycle, usually expressed in degrees.

Tone: A simple sound characterized by a sinusoidal waveform with specific attributes like amplitude, frequency, and phase.

Complex Sound: Any sound composed of multiple frequency components.

Spectrum: A description of the frequency components of sound, including amplitude spectrum (amplitude of each frequency component) and phase spectrum (phase of each frequency component).

Noise: A complex sound containing various frequency components, with its amplitude varying randomly.

White Noise: A type of noise in which all frequency components have the same average level, resulting in a constant energy distribution across frequencies.

2.3 Measurement Of Sound Pressure

Acoustic measurements are essential for evaluating and enhancing acoustic environments, involving a range of instruments from basic sound pressure level (SPL) meters to advanced spectral analyzers interfaced with computers. Ongoing developments have made these devices increasingly versatile and accessible [9].

The performance of acoustical instruments depends on key factors such as frequency response, dynamic range, crest factor capability, and response time. Frequency response

ensures accurate amplitude measurements across various frequencies, while dynamic range determines the instrument's ability to handle a broad range of signal amplitudes. Crest factor capability measures the instrument's ability to capture sudden peaks, and response time indicates how quickly the instrument can react to rapid signal changes. Together, these factors determine the accuracy and reliability of acoustic measurements [10-13].

2.3.1 The microphone

Microphones are crucial transducers that capture pressure fluctuations and convert them into electrical signals, playing a key role in the accuracy of acoustic measurements. There are four main types of microphones used in measurement applications: dynamic, ceramic, electret, and condenser microphones.

Dynamic Microphones: These microphones convert acoustic signals into electrical impulses using a diaphragm and coil placed in a magnetic field. They are relatively durable but are sensitive to magnetic interference and have a limited frequency response.

Ceramic Microphones: Ceramic microphones use a piezoelectric element to generate electrical signals from diaphragm vibrations. They are rugged and cost-effective, but they tend to have limited high-frequency response.

Electret Microphones: Electret microphones have a metal-coated plastic diaphragm, producing signals through capacitance variation. They offer good resistance to humidity but also have a limited frequency response.

Condenser Microphones: Condenser microphones consist of two charged plates with a diaphragm between them. They provide excellent high-frequency response, stability, and strong performance in extreme conditions but are susceptible to high humidity and can be mechanically fragile. [14]

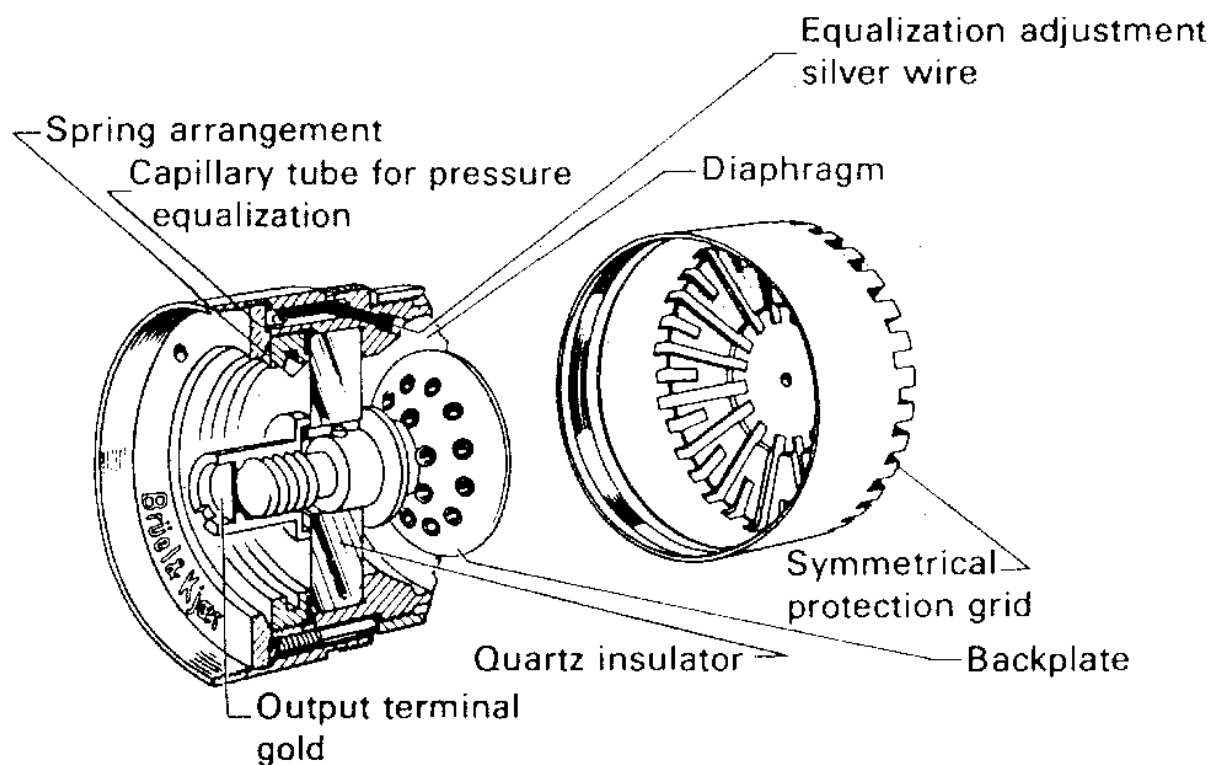


Fig 4 Principal elements of a condenser-microphone cartridge.[14]

3 Acoustical studies in Textiles

The growing awareness of environmental concerns has led many industries, particularly in high-income countries, to adopt more sustainable practices [15]. While earlier efforts focused primarily on using recycled products and eco-friendly packaging, there is now a shift towards viewing natural resources as valuable components that can enhance product quality. These resources often command premium prices due to their superior environmental attributes and compatibility with responsible production and disposal practices.

Sound absorption is becoming increasingly important, particularly in environments like automobiles and manufacturing facilities where noise control is critical [16-17]. Efficient and cost-effective sound-absorbing materials are essential to reduce unwanted noise. In the automotive industry, noise reduction is not only crucial for passenger comfort but also enhances the perceived value of vehicles, providing a competitive advantage. Traditional approaches have relied on high-weight sound-absorbing materials, which can negatively impact fuel efficiency and vehicle performance. Consequently, there is a growing emphasis on using lightweight and effective sound-absorbing materials [18-20].

One promising approach is the use of sound-absorbing materials in various vehicle components, such as floor coverings, door panels, and headliners. Nonwoven materials,

known for their lightweight, sound absorption efficiency, flexibility, and eco-friendliness, are gaining popularity in the automotive sector [21-22]. Natural fibers like cotton, milkweed, and kapok are particularly attractive due to their biodegradability and renewability, making them ideal for sound insulation and absorption [23-24]. However, research on blends of these natural fiber nonwoven fabrics for sound absorption remains limited, prompting this study to explore their potential as sound insulators and absorbers.

3.1 Acoustic Nonwoven Materials

Ganesan and T. Karthik [27] have taken significant steps toward developing eco-friendly nonwoven materials for acoustic applications. Their study revealed several important findings regarding the acoustic and thermal properties of nonwoven fabrics made from blends of cotton, kapok, and milkweed fibers.

First, as the proportion of kapok and milkweed increased in the blend, the bulk density of the fabric decreased due to increased sample thickness. This change in thickness significantly impacted sound reduction, as sound absorption increased linearly with a higher blend proportion of kapok and milkweed. Notably, cotton/milkweed-blended nonwovens outperformed cotton/kapok blends in terms of sound reduction. This was primarily due to the lower fiber density of milkweed, which provided more surface area for sound wave dispersion within the fabric.

The study also found that the distance between the fabric and the sound source played a crucial role in sound reduction. Sound reduction increased as the distance between the fabric and the sound source increased, particularly for fabrics with higher area density. Additionally, the research highlighted a strong correlation between lower fabric bulk density and increased sound reduction, underscoring the importance of fabric properties in determining sound absorption capabilities.

Lastly, the thermal conductivity of the samples decreased as the proportion of kapok and milkweed fibers in the blend increased. This decrease was attributed to the greater thickness and hollowness of these fibers, which resulted in improved thermal insulation properties for the nonwoven fabrics. These findings provide valuable insights into the potential applications of natural fiber-based nonwovens in both acoustic and thermal insulation contexts.

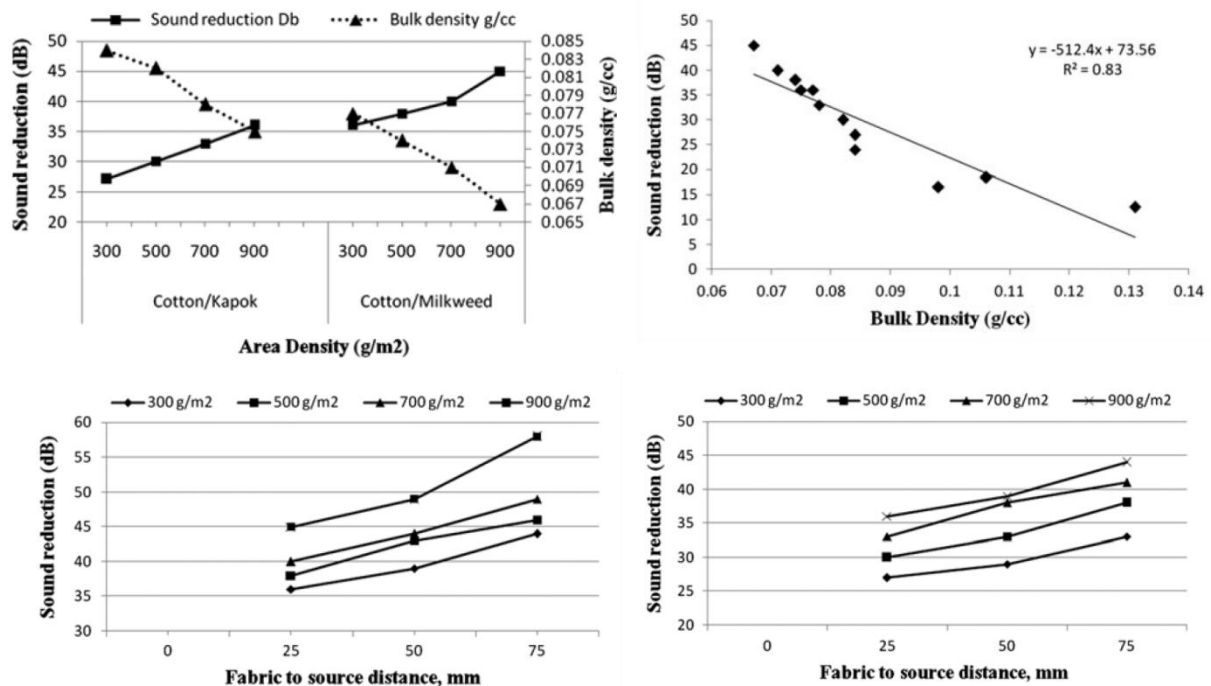


Fig.5 Effect of process variable on Sound reduction [27]

Parikh, Chen, and Sun [18] focused on utilizing natural fiber nonwoven floor coverings to reduce interior noise levels in automobiles, aiming to enhance acoustic comfort within vehicle cabins. The study explored the potential of these materials to improve in-cabin acoustic performance.

The paper discussed two commonly used methods for measuring the absorption performance of acoustical materials: ASTM E-1050 (Normal Incidence Sound Absorption) and ASTM C-423 (Random Incidence Sound Absorption). ASTM E-1050 is a cost-effective method that requires only a small sample to characterize absorption performance, while ASTM C-423 uses a large reverberant chamber and requires a larger sample, making it more representative of real-world absorption. In the study, ASTM E-1050 was used to evaluate the absorption capabilities of the nonwoven floor coverings. The absorption coefficient, which measures how much sound energy is dissipated and converted into heat as it passes through the material, was used to rank the noise reduction effectiveness of the materials. An impedance tube with dual microphones and a digital frequency analysis system was employed to determine the absorption coefficient and specific acoustic impedance ratios of the materials in

the frequency range of 100 to 3200 Hz.

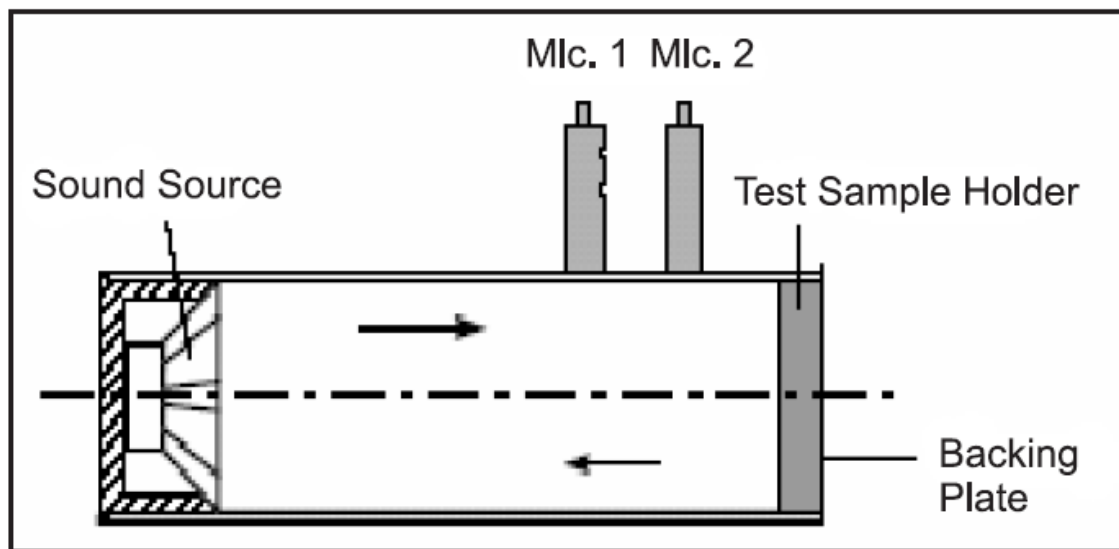


Fig.6The two-microphone impedance tube for Absorption testing.

Küçük and Korkmaz [28] in their published work, the focus is on investigating the impact of various physical parameters on the sound absorption properties of nonwoven composites made from a mixture of natural fibers. The study delves into understanding how factors such as fiber type, blend proportion, fabric thickness, and density affect the ability of these composites to absorb sound. Through comprehensive analysis and testing, the research sheds light on the relationships between these physical parameters and sound absorption performance, providing valuable insights into the development of effective and sustainable acoustic materials using natural fibers.

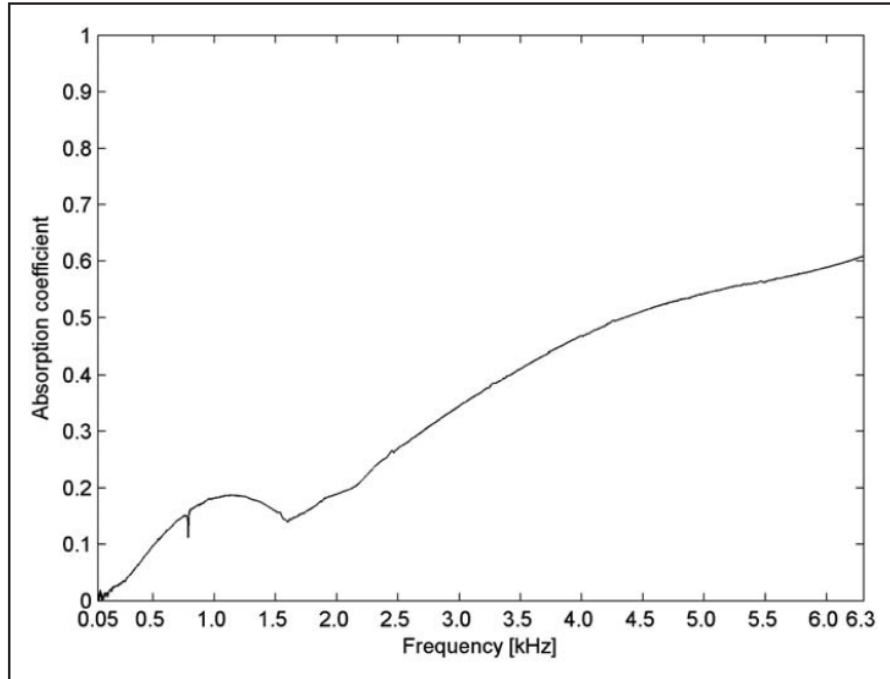


Fig.7 Sound absorption of commercial nonwoven mat. [28]

Küçük and Korkmaz [28] focused on investigating the impact of various physical parameters on the sound absorption properties of nonwoven composites made from a blend of natural fibers. The study explored how factors such as fiber type, blend proportion, fabric thickness, and density influence the ability of these composites to absorb sound. Through comprehensive analysis and testing, the research revealed the relationships between these physical parameters and sound absorption performance, providing valuable insights for developing effective and sustainable acoustic materials using natural fibers.

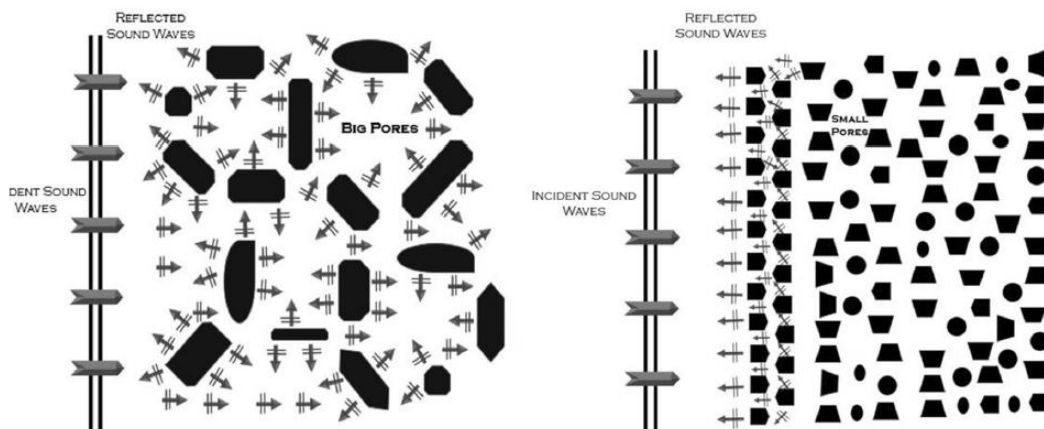


Fig.8 Sound absorption mechanism (decrease in energy transfer as pore size decreases from large to small) [29]

Tao, Ren, Zhang, and Peijs [31] present an extensive review highlighting recent advancements in the field of acoustic materials and noise control strategies. The paper covers a wide range of topics related to sound absorption and noise mitigation, including the development of novel acoustic materials, innovative manufacturing techniques, and effective noise control strategies. The review emphasizes the growing importance of acoustic materials across various applications and industries, shedding light on emerging trends and breakthroughs aimed at achieving quieter environments and enhanced acoustic performance. It serves as a valuable resource for researchers and practitioners seeking insights into the latest developments and strategies in noise control and acoustic materials.

4. Conclusion

The field of acoustics has transformed from an empirical art to a precision science, deeply integrated into modern life and industries. Nonwoven materials represent a revolutionary approach to addressing acoustic challenges, combining functionality with environmental responsibility. Natural fiber blends, such as those of kapok and milkweed, demonstrate significant potential in reducing sound transmission and improving thermal insulation. Studies reveal that the optimization of parameters such as blend proportion, density, and thickness can significantly enhance performance. While challenges remain in scalability and cost-effectiveness, advances in manufacturing techniques and theoretical modeling hold promise for overcoming these barriers. The growing demand for sustainable materials positions nonwovens as critical to the future of acoustic design and innovation, offering versatile solutions for automotive, construction, and industrial noise control. This review highlights the necessity of continued interdisciplinary research to unlock the full potential of nonwoven textiles in acoustic applications.

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