Acoustic Curtains: A Review of Sound-Blocking Mechanisms, Design Parameters, and Performance Benefits Using Polyurethane (PU) Coatings

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Abstract - This review analyzes the use of polyurethane (PU) coatings in acoustical curtain fabrics to improve sound absorption. As noise pollution becomes a more serious public health concern, there is a rising need for long-term, effective, and aesthetically beautiful noise control solutions in architectural, automotive, and industrial settings. This study summarizes recent research on the acoustic performance of textile-based absorbers, with a special emphasis on the synergistic use of PU coatings to adjust airflow resistance, surface density, and structural porosity. Key mechanisms of sound attenuation in coated fabrics are investigated, including viscous-thermal dissipation, resonant absorption, and impedance matching. Experimental techniques and predictive modeling approaches—such as the Johnson-Champoux-Allard (JCA) model, Pieren's equivalent circuit model, and finite element simulations—are thoroughly examined. The effect of PU coating characteristics such as coating %, thickness, distribution, and formulation on acoustic absorption spectra is thoroughly investigated.

This review also considers sustainability through the use of recovered PU materials and discusses future research directions, such as multifunctional coatings, smart acoustical fabrics, and scalable manufacturing processes. The findings demonstrate PU-coated fabrics' tremendous potential as high-performance, design-integrated acoustic materials for modern noise reduction.

Benefits, including thermal insulation, privacy enhancement, energy efficiency, and hygiene considerations, are also discussed. The review concludes that acoustic curtains represent an effective passive noise-control solution when properly designed, installed, and maintained, and highlights emerging research directions for future development.

Keywords: Acoustic curtains, noise pollution, sound absorption, polyurethane coating, airflow resistance, sustainable acoustics

1.INTRODUCTION

Noise pollution is recognized by the World Health Organization as a major environmental health risk, contributing to auditory and non-auditory effects such as sleep disturbance, cardiovascular disease, and cognitive impairment (Berglund et al., 1999) [1]. In response, there has been significant research into developing materials that can effectively absorb sound while meeting aesthetic, economic, and environmental criteria. Textiles, particularly curtain fabrics, offer a unique combination of functionality, flexibility, and visual appeal, making them ideal for interior noise control in residential, commercial, and institutional spaces (Seddeq et al., 2013; Tang et al., 2017) [2] & [3].

Traditional sound-absorbing materials like mineral wool, foam, and fiber panels often lack visual integration and may involve non-sustainable production processes. In contrast, textile-based absorbers can be seamlessly incorporated into interior design as curtains, drapes, wall coverings, and dividers. However, untreated woven fabrics typically exhibit limited acoustic absorption due to their low thickness and high porosity, which restrict viscous and thermal dissipation mechanisms (Soltani & Zerrebini, 2012) [4]. To enhance their acoustic performance, surface treatments and coatings have been explored, with polyurethane (PU) emerging as a particularly effective modifier due to its tuneable viscoelastic properties, adhesion versatility, and capacity to alter key acoustic parameters such as airflow resistance and surface density (Del Rey et al., 2020; Ekici et al., 2012) [5] & [6].

This review aims to consolidate and critically analyse the current state of knowledge on PU-coated acoustical curtain fabrics. It examines the underlying physical principles of sound absorption in coated textiles, reviews experimental and modelling methodologies, evaluates the impact of coating parameters on acoustic performance, and discusses sustainability and future trends. By

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integrating findings from recent studies—including those on recycled PU foams (Del Rey et al., 2020) [5]. Woven fabric acoustics (Tang et al., 2017) [3] this paper provides a comprehensive resource for researchers and practitioners in acoustical materials engineering.

Fig -1 Waterproof Polyester PU Coated Curtains

Indoor environments such as hospitals, schools, offices, and homes are particularly vulnerable to noise intrusion from both external and internal sources. In healthcare facilities, excessive noise has been linked to delayed patient recovery, increased stress among staff, and communication errors. Similarly, in educational and workplace settings, high noise levels reduce concentration, productivity, and overall comfort.

Traditional noise-control solutions—such as thick masonry walls, acoustic panels permanently fixed to walls, and double- or triple-glazed windows—are effective but often involve high costs, complex installation, and permanent structural changes. These limitations make them unsuitable for retrofitting existing buildings, rented spaces, heritage structures, or temporary installations.

In response to these challenges, acoustic curtains have gained increasing attention as a practical and adaptable noise-control solution. Acoustic curtains are specially engineered textile products made from dense, multi-layered materials designed to reduce sound transmission through absorption, reflection, and transmission loss mechanisms. Unlike conventional decorative curtains, acoustic curtains are developed using principles of acoustics and advanced textile engineering to achieve measurable noise reduction.

This review paper aims to consolidate and critically analyze the current body of literature on acoustic curtains. The focus is on understanding their sound-blocking mechanisms, material properties, design parameters, experimental performance, and practical applications. Particular attention is given to recent experimental studies that evaluate advanced materials, including PVC-based fabrics and multi-layer composites, in comparison with traditional woven and nonwoven curtain materials (Kumar et al., 2020; Kumar et al., 2021) [12] . The paper also highlights future research directions and emerging innovations in this field.

2. Fundamentals of Sound Absorption in Textiles

2.1 Mechanisms of Sound Absorption

Sound absorption in porous and fibrous materials primarily involves the conversion of acoustic energy into heat through viscous friction and thermal conduction within the material's pore structure. For thin textile fabrics, additional mechanisms such as membrane resonance and structural vibration also contribute, especially when backed by an air cavity (Pieren, 2012) [8] .

In untreated woven fabrics, the sound absorption coefficient at normal incidence is generally low ($\alpha_n <$ 0.3 across mid-frequencies) due to high air permeability and low flow resistance (Tang et al., 2017) [3] . Adding a coating such as PU modifies the fabric's microstructure by partially filling pores, increasing tortuosity, and adding viscoelastic mass, thereby enhancing energy dissipation (Del Rey et al., 2020) [5].

2.2. Key Acoustic Parameters

The acoustic performance of a coated fabric is governed by several intrinsic and extrinsic parameters:

- **Airflow Resistivity (σ)**: Defined as the resistance to airflow per unit thickness, it is directly related to viscous losses. PU coatings typically increase σ by reducing pore size and increasing path tortuosity (Allard & Champoux, 1992) [7] .

- **Surface Mass Density (m_f):** The mass per unit area affects the inertial behaviour and resonance frequency of the fabric membrane.
- **Porosity (ϕ) and Tortuosity (α_∞):** Describe the volumetric fraction of air and the complexity of the pore network, respectively.
- **Coating Thickness and Distribution**: Determine the uniformity and degree of pore closure, influencing both low- and high-frequency absorption.

The primary function of acoustic curtains is to reduce the transmission of sound waves between spaces. This is achieved through three fundamental acoustic mechanisms: sound absorption, sound reflection, and transmission loss.

Sound absorption occurs when acoustic energy enters a material and is converted into heat due to viscous friction and thermal losses within the material's porous structure. Porous and fibrous materials are particularly effective at absorbing mid- to high-frequency sounds (Everest & Pohlmann, 2015) [9].

Sound reflection takes place at the interface between air and the curtain surface. Differences in acoustic impedance cause part of the incident sound energy to be reflected back toward the source. Reflection contributes to overall noise reduction, especially when combined with absorption.

Transmission loss refers to the reduction in sound energy that passes through the curtain material. This mechanism is largely governed by the mass law, which states that heavier and denser materials provide greater resistance to sound transmission (Rossing, 2014) [10] .

2.2 Frequency-Dependent Behavior

The effectiveness of these mechanisms depends strongly on sound frequency. Low-frequency sounds have longer wavelengths and are more difficult to absorb, often requiring heavy and airtight barriers. Mid- and high-frequency sounds, such as human speech and office noise, are more easily absorbed by porous materials and multi-layer textile systems (Crocker, 2007) [11].

3. Material Science and Acoustic Performance

3.1 Materials Used in Acoustic Curtains

Material selection plays a critical role in determining the acoustic performance of curtains. Commonly used materials include dense woven polyester, velvet, mass-loaded vinyl (MLV), fiberglass, open-cell foams, and PVC-coated fabrics (Everest & Pohlmann, 2015) [9].

Dense fabrics provide mass for sound blocking, while porous layers enhance sound absorption. PVC coatings and MLV layers increase surface mass density and reduce air permeability, thereby improving transmission loss (Kumar et al., 2021) [12].
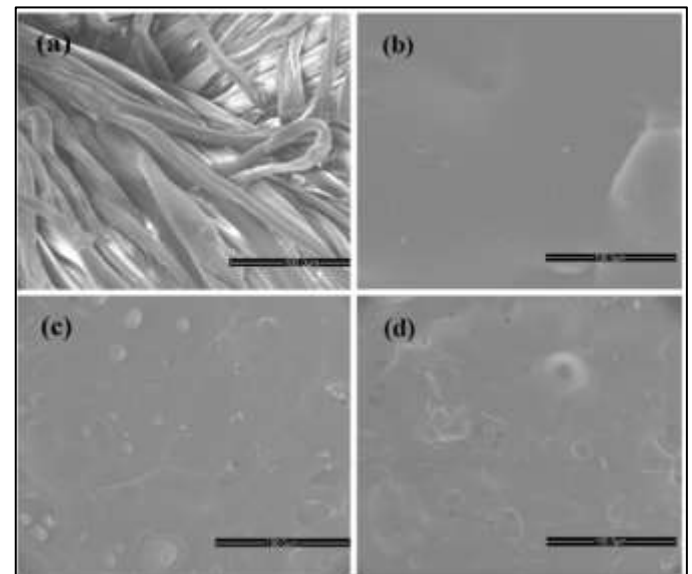

Fig -2 SEM images of a uncoated fabric vs PU-coated fabric

Polyurethane is a versatile polymer available in various forms—flexible foams, rigid sheets, sprays, and liquid coatings. Its acoustic utility stems from its viscoelastic behavior, which promotes mechanical damping, and its ability to form porous, semi-open structures when applied as a coating (Gama et al., 2017) [15]**.** PU can be derived from virgin or recycled sources, with recycled PU (RPU) offering environmental benefits without significantly compromising acoustic performance (Del Rey et al., 2020) [5].

3.2. Coating Application Methods

PU **coatings can be applied to textiles via:**

- **Knife coating**: For uniform layer deposition.

- **Spray coating**: For gradient or patterned applications.

- **Dip coating**: For full impregnation.

- **Screen printing**: For localized treatment.

The method influences coating penetration, thickness uniformity, and final acoustic behavior.

3.2 Surface Mass Density and Thickness

Surface mass density (kg/m²) is a key parameter influencing sound transmission loss. According to the mass law, doubling the surface mass density results in an approximate 6 dB increase in transmission loss at a given frequency (Rossing, 2014) [10]. However, increasing mass also increases curtain weight, which affects flexibility, usability, and mounting requirements.

3.3 Porosity and Microstructure

The internal microstructure of curtain materials—including fiber orientation, pore size, and elasticity—determines their absorption characteristics. Highly porous materials effectively absorb mid-to-high-frequency sounds, but excessive porosity may allow air and sound leakage, reducing overall insulation performance (Finkelstein et al., 2018) [14].

4. Influence of PU Coating Percentage on Acoustic Performance

4.1. Low Coating Percentage (5–15%)

At low coating levels, PU partially fills inter-yarn pores without fully sealing the fabric. This increases airflow resistivity moderately while maintaining some air permeability. Absorption improvements are most notable at mid-to-high frequencies (1000–4000 Hz) due to enhanced viscous effects (Soltani & Zerrebini, 2013) [16]. The fabric remains flexible and drapeable.

4.2. Medium Coating Percentage (15–30%)

A more significant pore closure occurs, substantially increasing σ and surface density. This shifts the absorption peak toward lower frequencies (500–2000 Hz) due to increased membrane mass and reduced Helmholtz resonance effects. The fabric begins to exhibit

characteristics of a double-porosity medium, as described by Olny and Boutin (2003) [17].

4.3. High Coating Percentage (>30%)

At high coating levels, the fabric approaches a membrane-like behavior with very low permeability. Sound absorption becomes dominated by mass-spring resonance, often resulting in narrow-band absorption peaks tunable by adjusting backing air cavity depth (Pieren, 2012) [8]. Flexibility may be reduced, impacting drapability.

4. Comparison with Traditional Sound Barriers

4.1 Advantages of Acoustic Curtains

Compared to rigid sound barriers such as walls and windows, acoustic curtains offer several advantages:

1. **Non-invasive installation**, suitable for rented or heritage buildings
2. **Flexibility and reconfigurability** for temporary or dynamic spaces
3. **Lower cost** compared to structural modifications
4. **Multifunctionality**, including thermal insulation, light control, and privacy enhancement (Asdrubali et al., 2017) [18].

4.2 Limitations

Despite their benefits, acoustic curtains generally provide lower sound insulation than rigid barriers, particularly at low frequencies. Their performance is highly sensitive to installation quality, coverage area, and edge sealing (Everest & Pohlmann, 2015) [9].

5. Design Parameters and Material Innovations

5.1 Multi-Layer Curtain Systems

Multi-layer designs represent a major advancement in acoustic curtain technology. By combining a heavy mass layer, an absorptive porous layer, and an impermeable membrane, curtains can achieve improved performance across a wider frequency range (Kumar et al., 2021) [12].

5.2 PVC-Coated and Composite Fabrics

Experimental studies show that PVC-coated polyester fabrics and composite curtains outperform lightweight woven fabrics. Kumar et al. (2021) [12] reported sound

transmission loss values of 11–22 dB in the 600–1600 Hz range for PVC-based curtains, compared to approximately 5 dB for standard hospital curtains.

6. Experimental Investigations and Performance Benchmarks

6.1 Laboratory Testing Methods

Acoustic performance is typically measured using impedance tube tests (EN ISO 10534-2) and reverberation room measurements (ASTM E90). These methods provide standardized data on sound absorption coefficients and transmission loss (Kumar et al., 2021) [12].

6.2 Performance in Healthcare and Residential Settings

Studies in hospital environments reveal that noise levels frequently exceed WHO guidelines. Advanced acoustic curtains significantly reduce noise exposure, improving patient comfort and staff working conditions (Kumar et al., 2020) [13].

7. Installation Strategies and Practical Considerations

Proper installation is critical for effective noise reduction. Curtains should provide full coverage, extend beyond openings, and include overlapping panels. Airtight sealing using Velcro, magnetic edges, or gaskets reduces sound leakage. Heavy-duty mounting hardware is essential to support curtain weight (Everest & Pohlmann, 2015) [9].

Applications and Multifunctionality

PU-coated acoustical curtains are used in:

- **Architectural acoustics:** Offices, theaters, hotels, and open-plan spaces.

- **Transportation:** Automotive interiors, aircraft cabins, and train compartments.

- **Industrial noise control:** Enclosures and partitions.

Multifunctional coatings can integrate:

- **Thermal insulation:** PU's low thermal conductivity enhances energy efficiency.
- **Flame retardancy:** Additives can improve fire safety.

- **Self-cleaning and antimicrobial properties:** For healthcare and hygiene-sensitive environments.

8. Cost-Effectiveness and Additional Benefits

Acoustic curtains offer strong economic advantages, particularly for retrofit applications. In addition to noise reduction, they improve thermal insulation and can reduce energy consumption by up to 25% (Asdrubali et al., 2017) [18]. They also enhance privacy, light control, and hygiene, especially in healthcare settings.

9. Maintenance, Longevity, and Sustainability

Regular vacuuming or dry cleaning is recommended to maintain acoustic performance. Harsh washing may damage internal layers. Sustainable materials such as recycled polyester are gaining interest, though performance trade-offs must be carefully evaluated.

10. Future Research Directions

Emerging research focuses on smart acoustic curtains, advanced textile composites, data-driven in-situ measurement techniques, and integration with building automation systems (Emmerich et al., 2025) [19]. These innovations are expected to further improve performance and adaptability.

1. **Smart Acoustical Textiles**: Incorporating phase-change materials, electroactive polymers, or micro-perforated adaptive layers for tunable absorption.
2. **Nanostructured PU Coatings**: Using nano-fillers (e.g., graphene, nanoclay) to enhance viscoelastic damping and mechanical strength.
3. **Hybrid Fabric Designs**: Combining PU coatings with underlying porous layers (e.g., nonwovens, recycled foams) for broadband absorption.
4. **Scalable Digital Fabrication**: Inkjet printing of PU patterns to create spatially graded acoustic properties.
5. **Improved Predictive Tools**: Machine learning models trained on extensive experimental datasets for rapid material design.

11. Conclusion

PU-coated curtain fabrics represent a promising intersection of acoustical engineering, materials science, and sustainable design. By modulating coating percentage, distribution, and formulation, significant enhancements in sound absorption can be achieved across targeted frequency ranges. Predictive models, particularly

those integrating fabric and coating properties, support the rational design of these materials. Future advancements will likely focus on multifunctionality, smart responsiveness, and greater use of recycled content, positioning PU-coated textiles as key components in next-generation noise control solutions.

Acoustic curtains are a practical, adaptable, and cost-effective solution for indoor noise control. Their effectiveness is based on established acoustic principles and enhanced by advances in material science and textile engineering. While not a replacement for structural soundproofing in all cases, acoustic curtains offer a valuable balance of performance, flexibility, and multifunctionality. Continued research and innovation will further expand their role in creating healthier and more comfortable indoor environments.

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