

A Review on Antimicrobial Textiles and Reusable Diapers: Hygiene, Comfort, and Sustainability

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Abstract- Antimicrobial textiles have revolutionized the modern textile industry by providing protection against microbial contamination while enhancing hygiene and durability. Their application in reusable diapers represents a critical innovation in infant hygiene, addressing issues such as diaper rash, infection risk, and environmental pollution associated with disposable products. This review explores the materials, mechanisms, fabrication methods, and performance of antimicrobial textiles, with a particular focus on reusable diapers. It also evaluates their safety, environmental impact, and future potential. Evidence suggests that antimicrobial fabrics significantly reduce microbial load and improve skin health, while reusable diapers offer a sustainable alternative to disposable hygiene products. However, challenges related to durability, safety of antimicrobial agents, and user practices remain.

Index terms: antimicrobial textiles, environmental impact, infant hygiene, reusable diapers, sustainable alternative

I. INTRODUCTION

Textiles are extensively used in healthcare and personal hygiene applications due to their versatility, comfort, and adaptability. However, they also provide a favorable environment for microbial growth, particularly when exposed to moisture, warmth, and organic matter. Under such conditions, microorganisms such as bacteria and fungi can proliferate rapidly, leading to fabric degradation, unpleasant odors, and potential health problems. This concern is especially significant in textiles that are in prolonged contact with human skin, where microbial contamination may contribute to infections and skin rashes [1,2].

It becomes a significant issue in the context of infant care, particularly in diaper usage. Diapers create a microenvironment characterized by high humidity, elevated temperature, and the presence of urine and fecal matter, which promote the growth of pathogenic microorganisms such as *Escherichia coli*, *Staphylococcus aureus*, and *Candida albicans*. Prolonged exposure to such conditions can lead to diaper dermatitis (diaper rash), which is one of the most commonly observed conditions in infants [3,4]. The disruption of the skin barrier in infants further increases susceptibility to infections, making hygiene and microbial control a critical requirement in diaper design.

Conventional disposable diapers have been widely adopted due to their convenience, high absorbency, and ease of use. However, their extensive use has raised significant environmental concerns. Disposable diapers are primarily composed of non-biodegradable materials such as polyethylene, polypropylene, and superabsorbent polymers, contributing to landfill waste and environmental pollution. It is estimated that billions of disposable diapers are discarded annually, with decomposition times extending over several decades [5,6]. In addition to environmental issues, certain chemical additives used in disposable diapers, like fragrances, dyes, and absorbent gels, have been associated with skin irritation and potential health concerns in sensitive individuals [7].

In response to these challenges, reusable diapers made from textile-based materials such as cotton, bamboo, and hemp have emerged as a sustainable alternative. These materials are biodegradable, breathable, and generally considered safer for prolonged skin contact. Reusable diaper systems typically consist of multiple

layers, including a soft inner layer, an absorbent core, and a protective outer layer, designed to provide comfort and functionality while minimizing environmental impact [8].

The incorporation of antimicrobials into textile-based reusable diapers represents a significant advancement in improving hygiene and infant health. Antimicrobial textiles are engineered using agents such as silver nanoparticles, zinc oxide, copper ions, or natural biopolymers like chitosan, which inhibit the growth of microorganisms through mechanisms such as disruption of cell membrane, inhibition of enzymes, and generation of reactive oxygen species [9,10]. By reducing microbial load, these fabrics can help in the prevention of diaper-related infections, minimizing odor formation, and enhancing overall user comfort.

Therefore, the integration of antimicrobial technologies into reusable diaper textiles offers a promising approach to addressing both health and environmental concerns. This intersection of textile innovation, microbiology, and sustainable design is increasingly gaining attention in both research and commercial sectors, highlighting the need for comprehensive evaluation of their effectiveness, safety, and long-term impact.

II. LITERATURE REVIEW

Antimicrobial Textiles: Concept and Development

Textiles, particularly those used in healthcare, sportswear, and intimate apparel, are highly susceptible to microbial contamination due to their high moisture content, sweat, and presence of organic matter. Studies have established that fabrics can act as carriers for pathogens which facilitate microbial growth and transmission if not treated appropriately [11].

To address this issue, antimicrobial textiles have been developed by incorporating agents that either inhibit the growth of microorganisms or eliminate microorganisms. These include synthetic compounds such as triclosan and quaternary ammonium compounds, as well as inorganic nanomaterials like silver (Ag), zinc oxide (ZnO), titanium dioxide (TiO₂), and copper nanoparticles. Among these, metallic

nanoparticles are widely used due to their broad-spectrum antimicrobial activity and long-lasting effects [11].

Nanotechnology has significantly advanced the field of antimicrobial textiles by enabling the development of fabrics with enhanced functionality, durability, and controlled release of antimicrobial agents. Medical textiles incorporating nanomaterials have shown improved performance in infection control and hygiene applications [12].

Mechanisms of Antimicrobial Action

The antimicrobial activity of treated textiles is primarily due to multiple mechanisms. Metal nanoparticles such as silver and copper release ions (Ag⁺, Cu²⁺) that disrupt microbial cell membranes, interfere with enzyme activity, and damage DNA, ultimately leading to cell death. Additionally, certain nanomaterials generate reactive oxygen species (ROS), which further enhance antimicrobial efficacy [11].

Experimental studies demonstrate that antimicrobial textiles can achieve up to 99.9% reduction in bacterial populations, including *Staphylococcus aureus* and *Escherichia coli*, confirming their effectiveness in real-world applications [13].

Types of Antimicrobial Agents Used in Textiles

Synthetic and Inorganic Agents

Synthetic antimicrobial agents and inorganic nanoparticles dominate current textile applications due to their high efficacy. Silver nanoparticles have gained importance because of their strong bactericidal properties and ability to function at low concentrations. Similarly, zinc oxide and titanium dioxide also provide antimicrobial effects [14].

Natural Antimicrobial Agents

Natural agents such as chitosan, plant extracts, and bio-based compounds have gained attention as eco-friendly alternatives. These materials are biodegradable, less toxic, and compatible with human skin. Research indicates that natural antimicrobial

finishes are increasingly preferred for personal hygiene textiles due to their safety profile, although their durability is often lower than synthetic counterparts [11].

Application of Antimicrobial Textiles in Hygiene Products

Antimicrobial textiles are widely used in the healthcare sector, where they have been shown to reduce microbial load and infection rates. A systematic review reported that textiles treated with nano agents of silver, copper, and zinc oxide significantly decrease microbial contamination compared to untreated fabrics [14].

In personal hygiene products such as diapers and sanitary napkins, antimicrobial textiles play a crucial role in preventing infections and maintaining skin health. The diaper environment, characterized by warmth, moisture, and organic matter, promotes microbial growth, increasing the risk of diaper rash, urinary tract infections, and candidiasis. Studies have demonstrated that incorporation of antimicrobial nanoparticles into cellulose-based materials used in diapers significantly reduces microbial growth, including multidrug-resistant strains [15].

Reusable Diapers and Textile Innovation

Reusable diapers have gained attention as sustainable alternatives to disposable diapers. Advances in textile engineering have enabled the development of high-performance reusable diapers using natural fibers and engineered fabrics. These products are designed with multiple layers to ensure absorbency, breathability, and leak protection while maintaining skin comfort.

Recent innovations include the use of nanocomposite-treated cellulose and advanced fiber structures, which enhance antimicrobial performance without compromising fabric properties. Studies show that such materials not only reduce microbial growth but also maintain effectiveness after repeated washing cycles, highlighting their potential for long-term use [13,15].

Durability and Wash Stability

One of the key challenges in antimicrobial textiles is maintaining effectiveness after repeated washings. Research indicates that fabrics with embedded nanoparticles exhibit significantly better durability compared to surface-coated fabrics, which tend to lose antimicrobial activity due to leaching. For example, embedded silver nanoparticle fabrics show minimal reduction in antimicrobial performance even after multiple wash cycles, whereas coated fabrics may lose up to 16% of their activity [13].

Similarly, nanocomposite cotton fabrics have demonstrated sustained antimicrobial activity (>98% bacterial reduction) even after repeated washings, emphasizing the importance of material engineering in improving durability [16].

Challenges and Safety Considerations

Despite their advantages, antimicrobial textiles present several challenges. The potential toxicity of nanoparticles, environmental concerns related to their release into water systems, and the risk of antimicrobial resistance are significant issues that require careful consideration.

Additionally, while synthetic antimicrobial agents offer high durability, natural alternatives are often preferred for applications involving prolonged skin contact, such as diapers, due to their lower risk of irritation and better biocompatibility [11].

Research Gaps and Future Scope

Although substantial progress has been made, gaps remain in understanding the long-term safety, environmental impact, and real-world effectiveness of antimicrobial textiles in reusable hygiene products. Future research should focus on areas such as development of biodegradable antimicrobial agents, long-term clinical studies on infant skin health, optimization of wash durability and sustainable manufacturing processes.

III. METHODOLOGY

This review adopts a systematic narrative approach to synthesize recent advances in antimicrobial textiles and their application in reusable diapers.

Data Sources and Search Strategy

A comprehensive literature search was conducted using major scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar. Keywords used in the search included “antimicrobial textiles,” “nanocomposite fabrics,” “reusable diapers,” “infant hygiene textiles,” and “antimicrobial nanomaterials 2023–2026.” Priority was given to peer-reviewed articles published between 2023 and 2026 to ensure inclusion of the most recent developments.

Inclusion and Exclusion Criteria

Inclusion criteria:

- Studies published between 2023 and 2026
- Research focusing on antimicrobial textile materials, nanocomposites, or hygiene products
- Studies evaluating effectiveness, durability, or safety of antimicrobial treatments
- Research involving textile-based hygiene applications such as diapers, wipes, or medical fabrics

Exclusion criteria:

- Studies lacking experimental validation
- Articles focusing solely on unrelated textile applications
- Non-peer-reviewed or non-scientific sources

Data Extraction and Classification

Relevant studies were screened and categorized based on:

- Type of antimicrobial agent (metal nanoparticles, natural agents, hybrid systems)
- Fabrication technique (coating, embedding, electrospinning, nanocomposite integration)
- Application (healthcare textiles, hygiene products, reusable diapers)
- Performance metrics (antimicrobial efficiency, durability, wash stability, safety)

Special emphasis was placed on studies involving nanocomposite-treated cellulose and cotton-based

materials, as these are commonly used in reusable diapers.

Analytical Framework

The collected data were analyzed using a comparative approach focusing on:

- Antimicrobial efficacy (percentage reduction in microbial load)
- Durability after repeated washing
- Biocompatibility and safety for skin contact
- Environmental sustainability

Recent experimental studies involving silver nanoparticle-embedded fibers, plant-based antimicrobial coatings, and hybrid nanocomposites were critically evaluated to identify trends and research gaps [11,13,17].

IV. RESULTS AND DISCUSSION

Effectiveness of Antimicrobial Textiles

Recent studies confirm that antimicrobial textiles exhibit high efficacy against a wide range of microorganisms, including *Escherichia coli* and *Staphylococcus aureus*. Fabrics embedded with silver nanoparticles demonstrate antimicrobial activity ranging from 92% to 99.9%, even after multiple wash cycles.

Similarly, nanocomposite cotton fibers capable of generating silver nanoparticles internally have shown strong and durable antimicrobial performance, highlighting the potential of self-functionalizing textile systems.

In hygiene applications such as diapers, nanocomposite coatings incorporating silver, copper, and zinc nanoparticles have been shown to significantly reduce microbial growth, thereby lowering the risk of skin infections and irritation.

Advances in Fabrication Techniques

Recent innovations in textile engineering have led to the development of advanced fabrication techniques that enhance antimicrobial performance. Embedded

nanocomposites provide superior durability and minimal leaching when compared to surface coatings. Techniques like electrospinning enable uniform distribution of antimicrobial agents within the fibers and bio-based coatings utilize plant extracts and chitosan for eco-friendly antimicrobial activity.

Electrospun fibers incorporating chitosan and silver nanocomposites have demonstrated improved mechanical strength and strong antimicrobial activity, making them suitable for biomedical and hygiene applications [18].

Additionally, biodegradable cotton fabrics treated with plant extracts and essential oils have shown effective antibacterial properties while maintaining environmental sustainability.

Application in Reusable Diapers

The integration of antimicrobial textiles into reusable diapers has shown promising outcomes. The diaper microenvironment—characterized by heat, moisture, and organic waste—creates ideal conditions for microbial growth. Incorporation of antimicrobial nanocomposites into cellulose-based diaper materials significantly reduces microbial load and prevents conditions such as diaper dermatitis.

Reusable diapers constructed from natural fibers such as cotton and bamboo, when combined with antimicrobial treatments, provide improved skin compatibility, reduced risk of infection and also enhance odor control. These properties make antimicrobial reusable diapers a viable alternative to disposable products.

Durability and Wash Stability

Durability remains a key factor in evaluating antimicrobial textiles. According to various studies embedded antimicrobial agents outperform surface-coated textiles in maintaining activity after repeated washing. Embedded silver nanoparticle fabrics show minimal loss (<1%) in antimicrobial activity after 30 washes whereas surface-coated fabrics may lose 11–16% effectiveness due to nanoparticle leaching.

This highlights the importance of selecting appropriate fabrication techniques for long-term applications such as reusable diapers.

Environmental and Sustainability Considerations

Recent research emphasizes the need for sustainable antimicrobial solutions. While metal nanoparticles offer high efficacy, their release into wastewater systems raises ecological concerns.

Bio-based antimicrobial materials derived from natural sources and waste valorization processes are emerging as promising alternatives. For instance, protein-based nanocomposites synthesized from industrial waste have demonstrated effective antimicrobial properties while supporting circular economy principles.

Reusable diapers themselves contribute significantly to sustainability by reducing landfill waste compared to disposable diapers.

Safety and Biocompatibility

Safety is a critical factor, particularly for infant applications. While antimicrobial textiles are effective, concerns remain regarding issues like nanoparticle toxicity, skin sensitivity in infants and long-term exposure effects.

Natural antimicrobial agents such as chitosan and plant extracts are increasingly preferred due to their biocompatibility and reduced toxicity.

Challenges and Research Gaps

Despite significant progress, several challenges persist. There exists limited long-term clinical studies on infant health. In addition to this, one of the major concerns is regarding the potential development of antimicrobial resistance. Furthermore, real-world performance data for antimicrobial reusable diapers remain limited, indicating a need for further applied research.

Future Directions

Future research should focus on:

- Development of biodegradable and non-toxic antimicrobial agents
- Integration of smart textiles with sensing capabilities
- Improvement in wash durability and cost-effectiveness
- Large-scale clinical validation for infant safety

V. CONCLUSION

Antimicrobial textiles play a vital role in enhancing hygiene and safety in reusable diapers. By reducing microbial growth and improving skin health, these materials address critical challenges in infant care. Reusable diapers, when combined with antimicrobial technology, offer a sustainable and effective alternative to disposable products. However, issues related to durability, environmental impact, and safety must be carefully managed. Continued research and innovation are essential to ensure safe, efficient, and eco-friendly solutions for modern hygiene needs.

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