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PHARMACEUTICAL INNOVATIONS IN MENSTRUAL HYGIENE: AREVIEW OF EMERGING TECHNOLOGIES IN SANITARY NAPKINS

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ABSTRACT

The demand for innovative and eco-friendly sanitary napkins is on the rise as awareness of harmful chemicals in conventional pads grows. This review article explores recent advancements in the development of sanitary napkins that incorporate antimicrobial, biodegradable, and eco-friendly materials. The study discusses a range of materials and technologies, including biomaterials, nanofibrous membranes, and liposomal microencapsulation, with a focus on their antibacterial properties and potential to reduce health and environmental risks. Key innovations such as essential oil-infused membranes, cannabidiol- coated cellulose, and nanosilver-incorporated pulp are highlighted for their contributions to hygiene and sustainability. The review provides a comprehensive overview of the current trends and future directions in sanitary napkin manufacturing, emphasizing the socioeconomic and environmental benefits of transitioningto advanced materials.

INTRODUCTION

Menstruation is a natural process experienced by women of reproductive age, involving the shedding of theuterine lining when pregnancy does not occur. This monthly cycle typically begins around age 12, known as menarche, and continues until menopause, which occurs between ages 45 and 55.[1] Proper menstrual hygiene management is essential for women's health, with sanitary napkins being a crucial product.[2] Traditional sanitary napkins, made from materials like rayon and viscose, often face challenges related to absorbency, comfort, and environmental sustainability.[3] Recent advancements in nanotechnology and microencapsulation offer promising solutions to these issues, aiming to enhance both performance and environmental impact.

Figure 1: Santitary Napkin.

Nanotechnology In Sanitary Napkins

Nanotechnology has significantly advanced sanitary napkin development by enhancing absorbency, comfort, and hygiene.

Importance of Nanotechnology

1. Enhanced Absorbency: Superabsorbent polymers (SAPs) enhanced with nanomaterials provide increased absorption capacity. Nanofibers and nanocomposite materials can absorb significantly more fluid, ensuring better management of menstrual flow and reducing leakage risks. Nanomaterials also enable the creation of ultra-thin, highly absorbent napkins, offering comfort without compromising effectiveness.

2. Improved Comfort: The use of smooth, thin nanofibers results in softer, more comfortable napkins, reducing skin irritation. Nanoporous materials improve air circulation, reducing moisture buildup and skin irritation.

3. Antibacterial Properties: Incorporation of antibacterial nanoparticles, such as silver nanoparticles, inhibits harmful bacteria growth, reducing infection risks. These nanoparticles also help neutralize odours, enhancing overall user comfort and confidence.[4]

4. Environmental Benefits: Nanotechnology promotes the development of biodegradable SAPs. These enable biodegradable sanitary napkins that decompose faster than traditional products, addressing concerns about microplastics and minimizing environmental impact.[5]

Microencapsulation In Sanitary Napkins

Microencapsulation is an advanced technique that offers significant benefits in sanitary napkins by enclosing active ingredients within microscopic capsules for controlled release.

Importance of Microencapsulation

1. Controlled Release: Incorporates antibacterial agents, fragrances, and skin-soothing compounds, providing prolonged protection and comfort.

2. Enhanced Absorbency: Superabsorbent polymers within microcapsules achieve superior absorbency, reducing the need for frequent changes.

3. Odour Control: Microencapsulated fragrances or odour-neutralizing agents manage and control odours, ensuring freshness.

4. Skin Protection: Skin-contacting layers enhanced with microencapsulated moisturizers or anti-inflammatory agents prevent irritation and rashes.

5. Safety and Stability: Encapsulation protects active ingredients from environmental degradation, ensuring effectiveness until needed.[3]

These advancements in nanotechnology and microencapsulation represent a significant leap forward in developing sanitary napkins, promising improved performance, comfort, and sustainability for users worldwide.

Menstrual hygiene products, such as sanitary napkins, have undergone significant transformations with the incorporation of advanced materials and technologies aimed at enhancing comfort, hygiene, and sustainability. This detailed review explores cutting-edge innovations including pH-responsive microencapsulated phase change materials (PCMs), eco-friendly napkins using plant-based fibers, silver nanoparticle-infused napkins, and electrospun cellulose acetate nanofibers. These developments represent a leap forward in menstrual hygiene by addressing health concerns, enhancing performance, and reducing environmental impact.

pH-Responsive Microencapsulated Phase Change Materials (PCMs)

In recent years, the integration of pH-responsive microencapsulated phase change materials (PCMs) in sanitary napkins has garnered attention due to their potential to significantly improve menstrual hygiene. This innovation focuses on combining n-eicosane, a phase change material that can store and release thermal energy, with poly(MAA-co-ACR-co-ACN), a pH-responsive polymer. Together, these materials create microcapsules with specialized functionalities that are particularly beneficial during menstruation. The primary challenge during menstruation is maintaining vaginal health, especially given that menstrual blood is more alkaline compared to the natural acidic environment of the vagina. This alkaline nature can lead to discomfort, irritation, and even an increased risk of infections. The incorporation of pH-responsive microcapsules in sanitary napkins aims to neutralize the alkaline nature of menstrual blood, helping maintain the vaginal pH at an optimal level. This not only prevents irritation but also supports vaginal health throughout the menstrual cycle.

Microencapsulation and Characterization: The microcapsules are synthesized through in-situ polymerization, a process that ensures the stable integration of the phase change material and the pH-responsive polymer. Characterization of these microcapsules is carried out using scanning electron microscopy (SEM) to observe their morphology, Fourier-transform infrared spectroscopy (FTIR) to identify functional groups, and thermogravimetric analysis (TGA) to assess their thermal stability.

Performance tests such as free swell capacity (FSC) and absorption under load (AUL) demonstrate that sanitary napkins containing these microcapsules exhibit significantly improved absorbency and comfort compared to conventional products. The PCMs also help regulate temperature, reducing discomfort from excessive heat during menstruation. This combination of pH responsiveness and thermal regulation makes PCMs a promising solution for enhancing both health and comfort in menstrual hygiene products.[6]

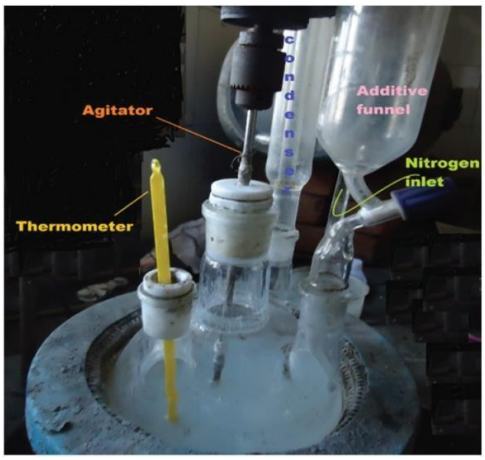

Figure 2: Assembly setup for preparing pH-responsivemicro-capsules.

Eco-Friendly Sanitary Napkins Using Plant-Based Fibers

Environmental sustainability has become a critical consideration in the design and production of menstrual hygiene products. Traditional sanitary napkins, often

made from synthetic materials, contribute significantly to environmental pollution due to their non-biodegradability. In response, researchers have developed eco-friendly sanitary napkins using plant-based fibers, offering a sustainable alternative without compromising on performance.

One of the most promising plant-based materials for sanitary napkins is Sansevieria trifasciata, commonly known as Snake Plant. This plant is known for its robust and strong fibers, which, when processed, can offer excellent absorbency and structural integrity. The fibers undergo pre-treatment processes, such as alkali treatment and bleaching, to enhance their absorption capacity and mechanical properties.

Figure 3: *Sansevieria trifasciata* leaves.

To further improve the hygienic properties of these eco-friendly napkins, Rosa damascena (Damask Rose) extract, known for its natural antimicrobial properties, is microencapsulated onto the plant-based fibers. This process ensures a controlled and sustained release of antimicrobial agents, providing continuous protection against pathogens such as *E. coli*, *Pseudomonas sp.*, and *Candida sp.*, which are common culprits of menstrual-related infections.

These plant-based sanitary napkins not only reduce the reliance on synthetic materials but also promote sustainability by being fully biodegradable. The napkins decompose within a few months, significantly reducing the environmental burden associated with menstrual waste. This innovation represents a major step toward promoting sustainable menstrual hygiene practices while maintaining high standards of comfortand hygiene.[7]

Microencapsulation of Cannabidiol (CBD) in Liposomes for Potential Sanitary Applications
Cannabidiol (CBD) has gained significant attention for its anti-inflammatory and analgesic properties, making it a promising candidate for menstrual pain relief. The microencapsulation of CBD in liposomes— small, spherical vesicles made from phospholipids—offers a way to enhance its bioavailability and enable targeted delivery to affected areas. This innovative approach is particularly relevant in sanitary products designed to address menstrual discomfort.

CBD's ability to reduce pain and inflammation stems from its interaction with the endocannabinoid system, which plays a crucial role in regulating pain, immune responses, and inflammation. When integrated into sanitary products, such as tampons or pads, CBD can provide localized relief from menstrual cramps, offering an alternative to systemic pain medications that may cause unwanted side effects.

Microencapsulation in liposomes helps protect CBD from degradation and ensures that it is released gradually over time, extending its therapeutic effects. Liposomal CBD has been shown to have higher bioavailability compared to non-encapsulated forms, making it more effective in delivering its benefits directly to the target area. This technology could revolutionize menstrual pain management by providing a natural and efficient method of pain relief directly where it is needed.

However, the integration of CBD into sanitary products also presents challenges, particularly in terms of regulatory approval and consumer acceptance. While CBD is generally considered safe, its use in feminine hygiene products is subject to stringent regulations, especially in markets where cannabis-derived productsare tightly controlled. Research is ongoing to address these challenges and to explore the optimal dosages and delivery mechanisms for effective menstrual pain relief.[3]

Nanofibrous Membranes Containing Essential Oils for Antimicrobial and Deodorizing Applications
Nanofibrous membranes are a new frontier in sanitary napkin technology, particularly for their ability to encapsulate and deliver essential oils, known for their potent antimicrobial and deodorizing properties. Tea tree oil, lavender oil, and eucalyptus oil are commonly used due to their natural antimicrobial activity, which can inhibit the growth of bacteria and fungi responsible for infections and unpleasant odors during menstruation.

Tea tree oil exhibits broad-spectrum antimicrobial properties against a range of bacteria and fungi, including *Staphylococcus aureus* and *Candida albicans*. Lavender oil is not only antimicrobial but also offers soothing effects, reducing skin irritation. Eucalyptus oil enhances the overall antimicrobial activity and provides a refreshing scent, making it a popular choice in hygiene products.

Nanofibrous membranes, produced via electrospinning, offer a high surface area and porosity, making them ideal carriers for essential oils. These membranes ensure controlled and sustained release of essential oils over time, providing long-lasting protection and deodorization. This sustained release mechanism is crucialin maintaining hygiene throughout the menstrual cycle, especially in extended wear situations.

Research shows that integrating essential oils into nanofibrous membranes significantly reduces microbial load and neutralizes odor-causing compounds. For example, studies have demonstrated that sanitary pads

with essential oil-infused membranes reduce bacterial counts by more than 99% within hours of use, providing superior hygiene compared to conventional pads.

While this technology presents numerous advantages, such as natural antimicrobial properties and sustainability, challenges remain. The stability of essential oils in different environmental conditions, such as temperature and humidity, is a concern, as these factors can affect the efficacy of the oils over time. Additionally, scalability and cost-effectiveness of incorporating essential oils into mass-produced sanitary products require further research.[2]

Silver Nanoparticle-Infused Sanitary Napkins

Silver nanoparticles have gained attention for their broad-spectrum antimicrobial properties. Recent advancements include the infusion of silver nanoparticles into sanitary napkins to enhance their antibacterial efficacy. The nanoparticles are incorporated into cellulose pulp, which is then used in the absorbent core of the napkin.

Characterization of these nanoparticles through transmission electron microscopy (TEM) and X-ray diffraction (XRD) reveals an average size of 10-20 nm and a face-centered cubic (FCC) crystalline structure.

Antibacterial efficacy tests using the Japanese Industrial Standards (JIS) L 1902 method show a significant reduction in bacterial colonies, particularly for *Staphylococcus aureus* and *Klebsiella pneumoniae*. Cytotoxicity studies confirm that these nanoparticles are non-toxic and biocompatible, making them safe for use in menstrual hygiene products.[5]

Electrospun Cellulose Acetate Nanofibers

Electrospinning technology has enabled the production of cellulose acetate (CA) nanofibers, which offer superior absorbency compared to conventional materials. These nanofibers, with diameters as small as 111.9 nm, provide a higher surface area-to-volume ratio, resulting in enhanced fluid absorption.

Field Emission Scanning Electron Microscopy (FESEM) and Brunauer-Emmett-Teller (BET) surface area measurements confirm the superior structural and absorption properties of CA nanofibers. Performance evaluations show that these nanofibers outperform both superabsorbent polymer (SAP)-encapsulated fibers and commercial sanitary napkins like Whisper and Stayfree.

In addition to their excellent absorption properties, CA nanofibers are biodegradable, contributing to the development of sustainable menstrual hygiene products. Their lower surface roughness and appropriate flexural rigidity offer superior comfort, making them an attractive alternative to conventional materials.[8]

Antimicrobial and Biodegradable Sanitary Pads with Nanomaterials Fused Polymers

Sanitary pads and diapers are widely used to manage menstrual and toilet secretions. Unfortunately, many commercial sanitary products contain harmful chemicals like sodium polyacrylate and dioxins, which are associated with adverse health effects. Additionally, the non-biodegradable nature of these products contributes significantly to environmental pollution. Recent advancements in biodegradable pads with antimicrobial properties offer promising solutions to these challenges. These innovative pads are made from lignocellulose-based, chemical-free, nanomaterial-fused polymers, which provide an eco-friendly alternative without compromising performance.

The materials utilized in these new sanitary pads include microbial growth media and chemicals from Hi Media laboratories. Copper, silver, and zinc oxide nanoparticles were synthesized and characterized using electron microscopy and X-ray diffraction. Moreover, pectinosone derived from orange peels and chitinosone from prawn shells were incorporated as coating materials, enhancing the pads' antimicrobial and absorptive properties. These pads consist of six layers, including an absorbent core made of holocellulose and lignocellulose, blended with nanoparticles, pectinosone, and chitinosone, which contribute to their high water-holding capacity and antimicrobial efficacy.

In terms of performance, the novel pads exhibited strong antimicrobial activity against *E. coli* and *Staphylococcus aureus*, along with a high water-holding capacity (37-40 mL) and a quick inlet time of 3.6 seconds. Importantly, they maintained a neutral pH and demonstrated no toxicity, making them safe for prolonged use. Furthermore, these pads are fully biodegradable, breaking down within three months, addressing both health and environmental concerns. This makes them a promising alternative to conventional commercial sanitary products.[4]

The rapid advancements in sanitary napkin technology bring exciting opportunities for improving menstrual hygiene. However, it is essential to address the health risks, socioeconomic challenges, and environmental impact associated with traditional menstrual products. Conventional pads, often made from synthetic materials and containing chemicals like adhesives, dyes, and fragrances, pose significant health risks. These chemicals can lead to skin irritation, allergic reactions, and even long-term health issues due to prolonged exposure. Additionally, the non-biodegradable nature of these products exacerbates environmental pollution, contributing to the vast accumulation of menstrual waste.

Socioeconomic and Health Benefits

Transitioning to eco-friendly sanitary products presents numerous socioeconomic benefits. The high cost of conventional menstrual products is a barrier for many

women, particularly in low-income regions. Eco-friendly alternatives, often made from locally sourced materials like organic cotton, bamboo, or plant-based fibers, can reduce costs and increase accessibility. This shift promotes menstrual equity, ensuring that more women have access to safe and affordable hygiene products. Furthermore, these products minimize exposure to harmful chemicals, reducing health risks and improving overall well-being. By fostering local production and reducing dependence on expensive, synthetic materials, these innovations can also create economic opportunities and empower communities.

Environmental Impact

The environmental impact of conventional sanitary products is profound, as these products contribute significantly to landfill waste due to their non-biodegradable nature. The average woman uses thousands of sanitary pads or tampons in her lifetime, most of which end up in landfills or oceans, where they can take hundreds of years to decompose. Eco-friendly alternatives, made from biodegradable materials, offer a solution to this growing problem. By using plant-based fibers and sustainable materials, these products not only break down more easily but also reduce the carbon footprint associated with their production and disposal. The adoption of biodegradable sanitary napkins and innovations like pH-responsive microcapsules and nanofibers can significantly reduce the ecological footprint of menstrual hygiene products.

Future Directions

The future of sanitary napkin technology lies in the continued exploration of sustainable materials and advanced functionalities. Researchers are focusing on developing biodegradable products that do not compromise performance or comfort. Innovations such as bio-polymer microencapsulation, essential oil- infused nanofibers, and biodegradable polymers infused with antimicrobial nanoparticles offer promising avenues for future research. Additionally, improving the scalability of these technologies will be crucial formaking eco-friendly products more widely available and affordable. As the industry evolves, collaboration between scientists, manufacturers, and policymakers will be essential to ensure that these advancements align with global sustainability goals and provide equitable access to safe menstrual hygiene products.

In conclusion, the shift towards eco-friendly and advanced technologies in sanitary napkin production is not just a trend but a necessity. By embracing these innovations, we can address the health, socioeconomic, and environmental challenges posed by traditional products. The industry must continue to prioritize sustainability, health, and accessibility to promote a cleaner, safer, and more equitable future for menstrual hygiene.

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