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Review Article

Fluid Imbibing Super Absorbent Textiles for Comfort Wear Performance

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Abstract

Textile is a basic human need, it not only provides the aesthetic appeal but also imparts necessary sweat absorption and relevant functional effects. The textile material is widely used for various hygiene and comfort wear applications where the absorption as well as leak proof retention of various body fluids is an essential parameter. This effect is achieved when the textile material is treated with suitable super absorbent chemicals. Superabsorbent finishes are polymeric coatings that significantly enhance the liquid absorption capacity of textile substrates. Known as superabsorbent polymers (SAPs), these materials can be natural, synthetic, or hybrid, characterized by their high degree of cross-linking and three-dimensional network structure. Capable of absorbing up to 100,000% of their weight in water, SAPs form stable hydrogels due to their hydrophilic groups. These properties make them suitable for diverse applications, including hygiene products, water purification, horticulture, and pharmaceuticals. In the past few decades, super absorbent polymers and fibres have found a lot of applications, especially in the field of textiles. This report briefly discusses the various application fields of SAP in textiles. With applications in hygiene products, medical textiles, protective apparel, automotive textiles, and geotextiles, the study explores how SAPs are incorporated into textile fibres (SAFs) to improve moisture absorption and management. Lastly, a comprehensive outlook for the future is given, highlighting encouraging prospects in SAP-based textile research and industry.

Keywords

Super Absorbent Fibres, Moisture Absorption, SAP Application in Textiles, Hydrogel, Hygiene Material, Protective Clothing

1. Introduction

Superabsorbent finishes are coatings of polymeric systems that have an enormous volume absorption capacity of water into their structure. When these finishes are applied, the capacity of textile substrates and other surfaces to absorb liquids is greatly enhanced.

They are also known as super absorbent polymers (SAPs). These polymers can be natural, synthetic, or hybrid [1]. Natural polymers like natural ones include chitosan, alginate, collagen, dextran, cellulose, and chitin; and artificial ones like polyethylene glycol, vinyl acetate, polyvinyl alcohol, acrylic acid, and methacrylic acid, are utilised to prepare SAP [2].

Superabsorbent polymers can be identified by their adequate degree of cross-linking and three-dimensional network structure. They can absorb and hold massive volumes of water or aqueous solutions [3], very big proportions (1000–100,000%) of water relative to their weight, to form a stable hydrogel. It is because of the hydrophilic groups they have connected to the polymeric backbone, such as hydroxyl,

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amino, and carboxyl groups [4, 5].

Due to their superior properties over conventional water-absorbing materials, superabsorbent hydrogels have extensive applications in the following areas: hygiene, sanitary napkins and other feminine hygiene products, disposable diapers, water purification, dye removal, coal dewatering, horticulture, biosensors, cement-based composites, fire-extinguishing gels, pharmaceutical administration, artificial snow, heavy metal ions removal, fibres and textiles, wound dressing, cementitious materials, and food preservation [6-9]. They are materials that can absorb liquids, such as brines, water, electrolyte solutions, urine, and biological fluids, including blood, sweat, and urine [10].

There is a huge demand for super-absorbent chemicals because of their application in multiple fields, such as medical textiles, agriculture, activewear, etc. Day by day, consumption increases, as shown in Figure 1. The concerning point is that most of the SAPs in the current market are not environmentally friendly; as people become increasingly aware of environmental hazards, there is an increase in demand for more sustainable products.

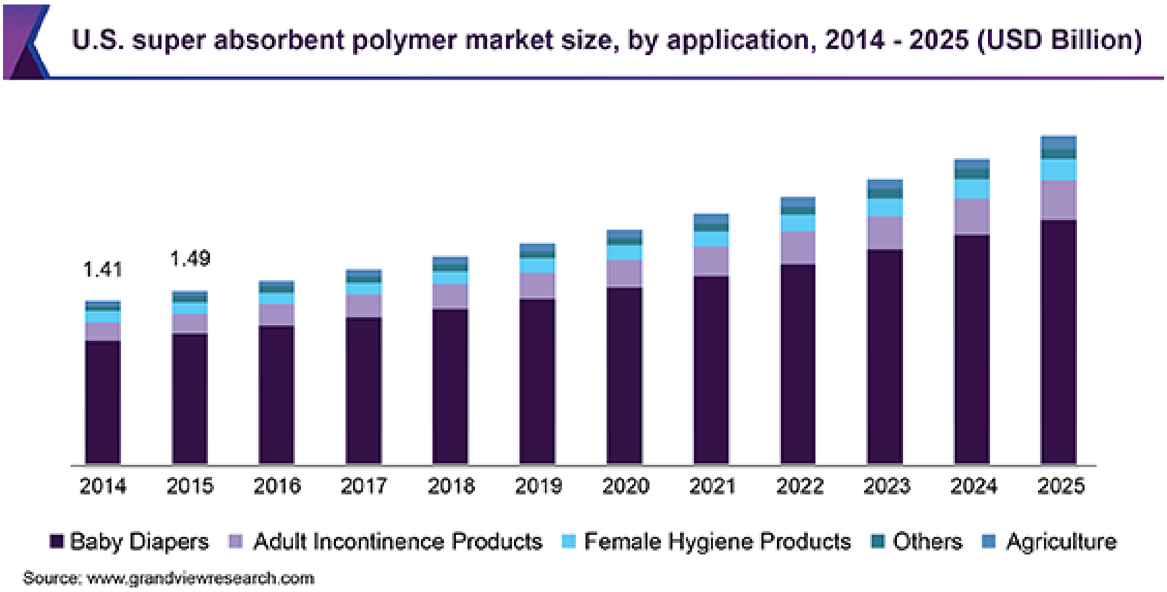

Figure 1. *Market Potential of Superabsorbent Textiles.*

2. Preparation Techniques

There are a few methods that can be utilised to prepare SAPs:

2.1. Bulk Polymerization

It is the most basic method, requiring monomers and initiators that are soluble in monomers.

This technique adds a small amount of cross-linker to the formulation, and UV catalysts, radiation, or chemical means are used to start the polymerization process. The suitable activator depends on the kind of monomer and solvents utilised. The polymerized product can be produced in various forms, such as films, particles, rods, emulsions, and membranes. This method's benefit is that it produces a very pure polymer with a large molecular weight [11].

2.2. Inverse Suspension Polymerization

It is known as inverted suspension because it is a water-in-oil method instead of the most popular oil-in-water process. This technique has two phases: an organic phase and an aqueous phase. The monomer, cross-linker, and initiator comprise the aqueous phase, whereas the solvent and stabiliser comprise the organic phase. It generates spherical SAP beads with particle sizes ranging from 1 micron to 1 mm, hence obtaining direct powder or beads [12].

2.3. Solution Polymerisation / Gel Polymerisation

Creating super absorbents primarily involves the solution copolymerisation or free radical-induced polymerisation of acrylic acid and its salts with acrylamide and a cross-linking agent.

Compared to bulk polymerisation, this method has the advantage that the solvent works as a heat sink/ promotes heat transfer and controls viscosity [13].

2.4. Radiation Polymerisation

Ionising high-energy radiation, such as electron beams and gamma rays, is utilised to initiate the polymerization process that produces SAPs of unsaturated chemicals. Since no chemical initiator is used in this process, the product obtained is quite pure, which gives it an advantage over a chemical initiator [14].

The most often used synthetic method is the free-radical cross-linking copolymerisation of acrylamide. This hydrophilic non-ionic monomer is combined with an ionic co-monomer to boost its swelling capacity and a small cross-linking agent [15].

Categorisation based on fundamental components

The basic classification for SAP lies in their origin, which is discussed in Table 1.

Table 1. *Classification of SAP based on their origin.*

Natural			**Synthetic**
SAP derived from plant and plant-based material	**SAP derived from animal-based material**	**SAP derived from algae**	**SAP derived from synthetic monomers**
Cellulose-based SAP (Baby Diapers, Medical Textiles and Feminine Hygiene Products)	Gelatine based SAP	Alginate based SAP (Geotextile)	Acrylic Acid, Methacrylate (Industrial and Automotive Textile) Acrylamide, Potassium acrylate (Geotextile) Polyacrylate (Protective Textile)
Starch-based SAP (Geotextile)	Chitosan-based SAP (Medical Textile)		Methacrylic acid (MAA), Methacrylate agarose (Hygiene products)
Lignin based SAP			
Pectin based SAP			
Guar gum-based SAP			

3. Common SAP Used in Textiles

Over the past few decades, SAP has been employed extensively in textiles. Items for bodily fluids and exudates, such as sanitary towels, diapers, incontinence pads, and medical sponges, are among the most popular textile-based superabsorbent materials. Some commonly used SAP in textiles is discussed below:

3.1. Cellulose-based SAPs

Carboxymethyl Cellulose, Hydroxyethyl Cellulose, Hydroxymethyl Cellulose, and Hydroxypropyl Methyl Cellulose all play a crucial role in formulating Cellulose-based SAPs.

Swelling and, ultimately, solubility are caused by substituting the hydroxyl group with other groups, such as carboxymethyl, on the cellulose backbone, which significantly alters the properties of cellulose and the gel network forms when the molecular weight surpasses a critical value.

Carboxymethyl cellulose, a biodegradable and water-soluble cellulose derivative, would be a useful precursor to produce bio-SAP [16] The bio-SAPs can be created by crosslinking carboxymethyl cellulose from recovered cardboard or cellulose fibers used as raw materials [17].

3.2. Chitosan-based SAPs

Chitosan contains carboxyl (–COOH) and amino (–NH3) groups and serves as the synthesis of SAP. These groups make graft polymerised hydrophilic vinyl monomer chains easier onto CS, which is an effective method of creating more biodegradable hydrogels [18]. According to Chadha et al., CS can enhance shelf life and is anti-bacterial, anti-fungal, biodegradable, biocompatible, and non-volatile. It is safe for the human body and the environment and hence plays a crucial role in the textile industry [19].

3.3. Starch-based SAPs

Strach is a complex heterogenous carbohydrate material composed of amylose and amylopectin, having molecular weights 10^6 and 10^8, respectively. The absorbency property is influenced by the composition of the SAP's amylose/amylopectin ratio and the lengthening of the grafting segment as the concentration of amylopectin in starch increases. The superabsorbent material composed of polysaccharide, polyacrylic acid, and cassava starch exposed to gamma radiation exhibited a biodegradation rate of approximately 42%. This is a significant degrading feature of starch-based SAPs, as incorporating starch into the material enhanced its biodegradability [20].

3.4. Alginate-based SAPs

Alginic acid, a polysaccharide, is a linear copolymer that is covalently attached to homo polymeric block residues (L- and D-glucuronic acids). It is mostly found in brown algae and has a very hydrophilic look that turns into sticky gum after absorption. Salts are referred to as alginate when mixed with metallic components such as calcium and sodium. The powdered form of alginate, obtained from a specific species of brown seaweed, has a colour spectrum that includes white and yellowish-brown. Sodium alginate is a relatively low-cost, biobased polymer extensively used in food, pharmaceutical, agricultural, and textiles [21]. It is also biocompatible and low in toxicity.

4. Super Absorbent Fibres (SAF)

There are various forms of superabsorbent polymers (SAPs), including SAP powder, SAP granules, and SAP fibers. Of these, superabsorbent fiber is easier to handle during processing and may absorb liquids more quickly than powders or granules due to its fibrous structure. This fiber can be spun into yarn and either knitted or woven, alone or blended with other fibers, to meet specific end-use requirements.

Additionally, SAF can be produced at micro or nanoscale, which increases surface area and enhances both absorption and vapor transmission properties.

4.1. Combining SAP with Hydrophobic/Hydrophilic Textile Material

Certain superabsorbent fibers are produced by blending SAP with other materials. For example, Lanseal® F consists of an outer SAP layer and an inner core of acrylic fiber. Upon exposure to water, the outer SAP layer absorbs the moisture and expands [22].

4.2. Direct Application of SAP in Superabsorbent Fiber Manufacturing

In the textile industry, synthetic fibers can be produced through various methods such as wet spinning, dry spinning, melt spinning, and dry-wet spinning. For micro-superabsorbent fibers, wet and dry spinning are commonly used. Additionally, nano-superabsorbent fibers can be created using the electrospinning technique [23].

5. Applications of SAP in Textiles

In Textiles, the major application of super-absorbent finishes is in fields such as

1. Baby Diapers
2. Medical Textiles
3. Feminine Hygiene Products
4. Geotextiles (Soil contamination and moisture control)
5. Protective Clothing (Chemical, Heat and Cold Protective Clothing)
6. Automotive and Industrial Textile (Moisture Absorbtion in Car seat, Industrial effluent treatment)
7. Active Wear (Sweat Control)

Medical textiles are one of the higher fields that consume a lot of super-absorbent chemicals, however, there are several other fields in textiles where the SAP finds its applications.

Some areas where super absorbent finishes are applied are:-

5.1. Baby Diapers

The diaper industry was changed by the adoption of superabsorbent polymers. Disposable diapers are primarily made of an absorbent pad, or "core," encased in two layers of non-woven fabric that transfer moisture to the diaper's hydrophilic core while protecting the baby's skin [24, 25]. About 30 times their weight in urine is absorbed and retained by SAP when subjected to a small amount of mechanical pressure. The swelling gel keeps the liquid from seeping onto the baby's skin or clothes in a firm, rubbery form [26]. In 2023, the diaper market in the world was valued at US$85.2 billion. The IMARC Group estimates that the market will increase from 2024 to 2032, when it reaches US$ 159.3 billion, at a CAGR of 7% towards sustainability and putting these consumer goods among the most prevalent items in landfills. Several studies have been conducted to replace diaper material with bio-based and environmentally friendly material [27].

5.2. Adult Incontinence Product

Superabsorbent polymers can be fixed into any desired arrangement in one or more sheets to create sheet-like absorbents for water and aqueous solutions. These absorbents can be used in various technical and industrial applications, including hygienic products like adult incontinence products, baby diapers, and wound dressings. The preferred SAP materials include copolymers and partially neutralised, slightly cross-linked polymers of acrylic acid and acrylamide, starch graft polymerise, cross-linked starches, and cellulose derivatives.

5.3. Hydrogel Dressings

Moist hydrogel dressings are made from a combination of synthetic (polyethylene glycol) and poly (vinyl pyrrolidone) and natural (agar-agar, gelatine, and pectin) polymers placed in commercial packaging and sterilised using an electron beam or gamma radiation. The most popular dressing for burns is hydrogel, which is additionally frequently employed for traumatic wounds, ulcerations, and bedsores. They are versatile and can be used on any body part. The hydrogel dressing is easy to remove and causes no pain. When using this type of dressing, skin regeneration, and reconstruction occur more quickly during the healing process than conventional dressings [28].

5.4. Covers for Operating Room Tables

Materials utilised in the healthcare setting can be treated with superabsorbent. These covers form a barrier impenetrable to bacteria, viruses, and bodily fluids, improving patient, healthcare worker, and equipment protection.

Tri-laminate textiles also aggressively trap and lock fluids into the superabsorbent core, thereby preventing cross-contamination of fluid run-off. By wicking away fluids and keeping them in the core, the material also helps to reduce exposure to moisture and preserves the integrity of the patient's skin [29].

5.5. Protective Clothing

Protective clothing in high-risk environments, such as for firefighters, is crucial but often uncomfortable due to multiple layers that limit water vapor permeability, preventing heat loss and causing sweat buildup. This leads to thermal strain and discomfort, prompting research into using super absorbent polymers to enhance wearer comfort.

Several researchers explored that blended fabric combining polyacrylate with the existing Nomex® and Kevlar® material can improve sweat absorption and promote faster drying, enhancing comfort and reducing thermal strain in protective clothing systems, especially for firefighters [30, 31].

Chemical protective clothing (CPC) is designed to shield individuals from dangerous chemicals, serving as the final defense in chemical handling tasks. It must ensure safety while maintaining wearer comfort. Sodium polyacrylate is added to CPC to improve moisture vapor transmission and enhance wearer comfort. The PU and SAP coating on cotton fabric effectively blocks water and liquid chemicals. SAP's hydrophilic properties also improve evaporative transmittance, providing better thermal comfort [32].

5.6. Geotextiles

SAP has been rigorously used in multiple applications when it comes to the absorbent geotextile. A water-absorbing geocomposite is made from geotextile wrapped around a synthetic core with superabsorbent polymer (Acrylamide and potassium acrylate) inside, which makes the water easily available for plants in the climate extremities [33].

One potential solution for cleaning and improving contaminated soil is the use of superabsorbent geotextiles. These materials help separate crude oil from the soil, effectively reducing pollution while also enhancing soil properties, such as shear strength [34].

SAF made of Polyacrylamide (PAM) is significantly used as a soil erosion control agent in irrigation and conservation systems. The concept of producing fibers from PAM by electrospinning is particularly intriguing, as the shift from granular to fibrous structures would significantly increase the surface area per unit mass [35].

5.7. Automotive and Industrial Textiles

Thermal Comfort in Car Seats can be enhanced by using a superabsorbent fibrous web (made by using acrylic acid (AA), methylacrylate (MA) and a small quantity of special acrylate/methylacrylate monomer (SAMM)) that is thin yet possesses high moisture absorption capabilities and is particularly effective at absorbing and releasing water vapor in conditions of both very high and very low humidity [36]

SAP plays a crucial role in removing toxic heavy metal pollutant ions from industrial effluents. Their swelling characteristics allow them to effectively capture and retain these harmful ions, which is essential for treating contaminated water. SAPs can also aid in the elimination of synthetic dyes alongside heavy metal ions, thereby improving the overall treatment of industrial effluents and contributing to environmental protection [36].

5.8. Active Wear

Active-wear textiles are primarily used by active or sports person as their high body activity requires easy transportation of sweat and heat to the environment while maintaining comfort**.** E.g. Three-layered functional sweat pads (FSP) consist of an inner layer made from an optimized Coolmax/polypropylene nonwoven blend treated with antimicrobial ZnO and embedded with superabsorbent polymer (SAP) [37].

6. Summary

SAP represents a groundbreaking advancement in material science, offering extraordinary liquid absorption capabilities that significantly enhance the liquid retention capacity of various substrates. These versatile polymers can be categorized into natural derivatives, such as chitosan, alginate, and cellulose, and synthetic alternatives, including polyethylene glycol and acrylic acid. Their remarkable absorbent properties have led to widespread applications across multiple sectors, including hygiene products, medical textiles, water purification, and environmental remediation.

The synthesis of SAPs employs several advanced techniques, including bulk polymerization, inverse suspension polymerization, solution polymerization, and radiation polymerization. Each method presents unique advantages, such as the production of high-purity polymers or the ability to tailor the physical characteristics of the final product. Within the textile industry, commonly utilized SAPs encompass cellulose-based, chitosan-based, starch-based, and alginate-based variants, each imparting distinct properties that cater to specific applications.

Among the various forms of SAPs, superabsorbent fibres (SAFs) stand out due to their enhanced processing ease and superior absorption rates, attributed to their fibrous structure. SAFs can be intricately spun into yarn and seamlessly blended with other fibres to fulfil specific performance criteria. Furthermore, the ability to fabricate SAFs at micro or nanoscale dimensions further augments their absorption and vapor transmission characteristics, making them highly effective in specialized applications.

The applications of SAPs in textiles are both diverse and impactful. In the baby diaper industry, the incorporation of SAPs has revolutionized product design by significantly enhancing absorbency and leak prevention, ensuring comfort for infants. Adult incontinence products leverage the high absorbency of SAPs, while hydrogel dressings, composed of SAPs, provide optimal moisture retention for wound care, promoting healing. Additionally, SAPs improve the functionality of protective clothing, facilitating moisture management and comfort, particularly in high-risk environments.

In the realm of geotextiles, SAPs contribute to soil moisture retention and pollution remediation by effectively isolating contaminants from the soil. Automotive and industrial textiles employ superabsorbent fibrous webs to enhance thermal comfort in car seats, adeptly managing moisture across a spectrum of humidity conditions. Moreover, SAPs play a pivotal role in environmental conservation by effectively removing toxic heavy metal ions and synthetic dyes from industrial effluents, thereby promoting cleaner water systems.

7. Future Scope

The future of superabsorbent finishes is promising, with several key avenues for exploration and development. The ongoing demand for environmentally sustainable materials is likely to drive research into biodegradable and bio-based SAPs, fostering a transition towards greener alternatives in industrial applications. Additionally, the potential integration of SAPs with smart textiles, which respond dynamically to environmental changes, could revolutionize applications in activewear and healthcare, enhancing comfort and functionality.

Advancements in nanotechnology may also pave the way for the development of next-generation superabsorbent fibres with enhanced performance characteristics, including improved absorption rates and rapid moisture vapor transmission. Furthermore, as the textile industry increasingly focuses on circular economy principles, the recycling and upcycling of SAP materials could emerge as a vital area of study, contributing to waste reduction and resource efficiency.

In conclusion, the field of superabsorbent finishes is ripe with potential, and continued research in this area will likely lead to innovative solutions that address both current and future challenges across various industries.

Abbreviations

SAP	Super Absorbent Polymer
SAF	Super Absorbent Fibre
AA	Acrylic Acid
AM	Acrylamide
MA	Methylacrylate
SAMM	Special Acrylate/Methylacrylate Monomer
CAGR	Compound Annual Growth Rate
CPC	Chemical Protective Clothing
PU	Polyurethane
PAM	Polyacrylamide

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Author Contributions

Richa Khulbe: Formal Analysis, Writing – original draft

Ashok Athalye: Conceptualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Fields

Richa Khulbe: PhD Research Scholar, Recycling of PET for textile applications, Development of Vegan Leather, Segregation & sorting of Textile waste, Sustainability in Textile

Ashok Athalye: Sustainable textile processing, Eco-friendly alternatives to synthetic chemicals, Varolising textile Waste, Developing Green Firecrackers from Cellulosic waste, Effluent treatment and characterization, Functionalising textiles for Technical applications