CHAPTER 2

LITERATURE REVIEW

2.1 Technical Textiles Market – An Overview

Since the beginning, humans have used various textiles as apparels for comfort, protection and personality improvement. Traditionally various garments have been used for their aesthetic appeal whereas household textiles for ease of the life and as decorative elements as well. The use of fabrics evolved dramatically in the 19th century. Unlike conventional textiles, these textile products primarily utilised for their functional performance better known as technical textiles. The technical textiles are mostly used due to their distinctive physical and functional attributes in diverse applications [10, 11]. The definition of technical textiles adopted by the authoritative *Textile Terms and Definitions*, published by the Textile Institute, is 'textile materials and products manufactured primarily for their technical and performance properties rather than their aesthetic or decorative characteristics'.

Although 'technical' textiles have attracted considerable attention, the use of fibres, yarns and fabrics for applications other than clothing and furnishing is not a new phenomenon. Recently the technical textiles are getting a lot of attention because of the wide variety of applications. It is not exclusively linked to the emergence of modern artificial fibres and textiles. For many years, a variety of natural fibres such as flax, cotton, sisal, and jute have been utilised in applications such as tents, tarpaulins, sacking, ropes, sailcloth etc. Romans first used cotton woven fabrics and meshes to make the unstable, damp soil to construct the stable roads. With the advent of the synthetic polymers, geotextiles and geogrids have been further developed for various civil engineering applications known as "Geosynthetic".

The textile industry is expanding its boundaries using wide range of the fibres and processes in to diverse range of products which makes it actually hard to exactly define the textile sector. The traditional and home textile businesses are now diversify in to different technical textiles for applications such as automotive, construction, agriculture etc. in general and medical, healthcare and in particular [12]. The leading international trade exhibition for technical textiles, Techtextil (organised biennially since the late 1980s by Messe Frankfurt in Germany and also in Osaka, Japan), defines 12 main application areas: [11, 13]

• Agrotech: agriculture, aquaculture, horticulture and forestry
• Buildtech: building and construction
• Clothtech: technical components of footwear and clothing
• Geotech: geotextiles and civil engineering
• Hometech: technical components of furniture, household textiles and floorcoverings
• Indutech: filtration, conveying, cleaning and other industrial uses
• Medtech: hygiene and medical
• Mobiltech: automobiles, shipping, railways and aerospace
• Oekotech: environmental protection
• Packtech: packaging
• Protech: personal and property protection
• Sporttech: sport and leisure

2.1.1 Technical Textiles Market

Due to economic growth worldwide the demand for technical textiles is increasing due to its cost effectiveness, long-lasting nature, convenience of use, and environmentally friendly characteristics. Fig. 2.1 shows the share of the various types of the technical textiles in the global market in the year 2019-20. Among the various categories, Mobiltech, Indutech, Packtech and Meditech collectively account for more than 50% of the global market. Fig. 2.2 shows the region-wise global consumption of technical textiles. USA and Europe consumes double (45%) as compared to Asian counterparts: China, Japan and India (23%). The industry projects are already in advancements in the Asian counties including China and India [14].

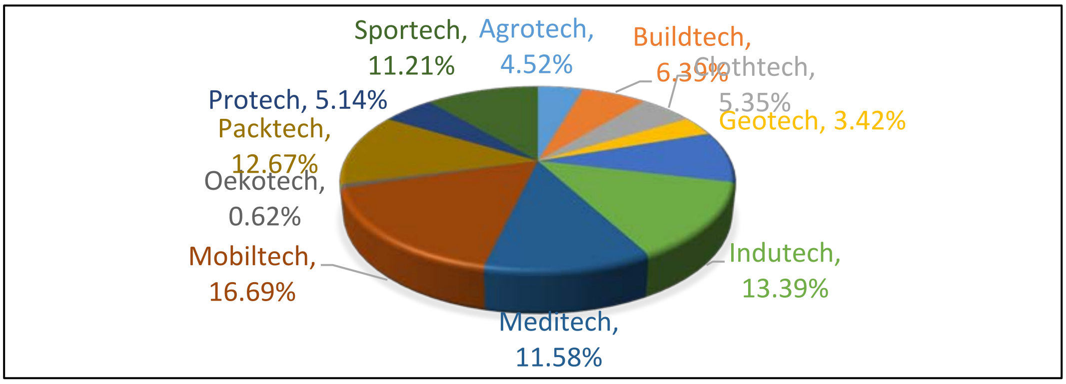


Fig. 2.1 Global market of technical textiles (2019-20)

Post-covide19 scenario shows that there is very high potential for India to progress in this field. The government's strategic approach and policies have significantly influenced the growth of the technical textile market. Developing nations like Taiwan, Brazil, Korea, and India import products from the US. These nations find it difficult to increase their market share through modernization, expansion, and research. The United States is expected to face competition from rapidly developing nations in the near future. When compared to the traditional textile industry, the technical textile market is expanding at an exponential rate.

According to the report on "Technical Textiles Industry in India: Opportunities and Challenges" the share of technical textiles is only17% of the overall textile market (Fig 2.3).

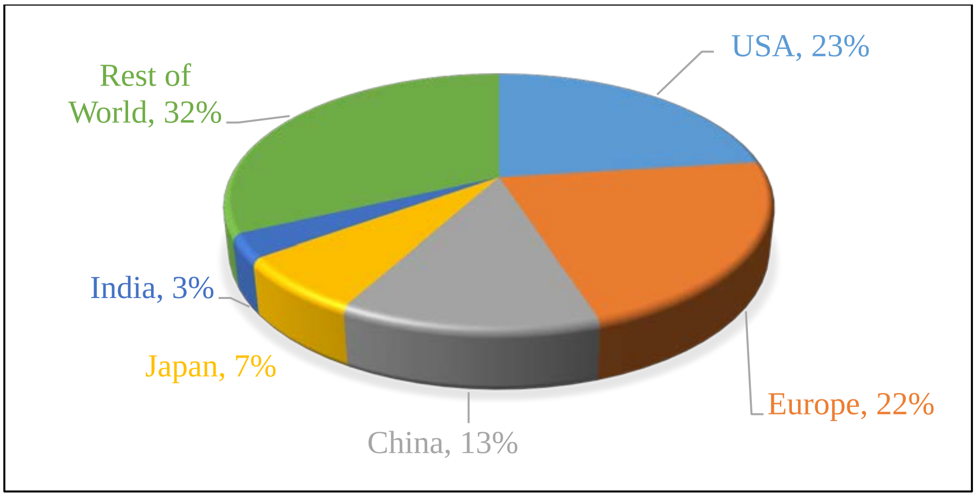


Fig. 2.2 Region wise global consumption of technical textiles (2019-20)

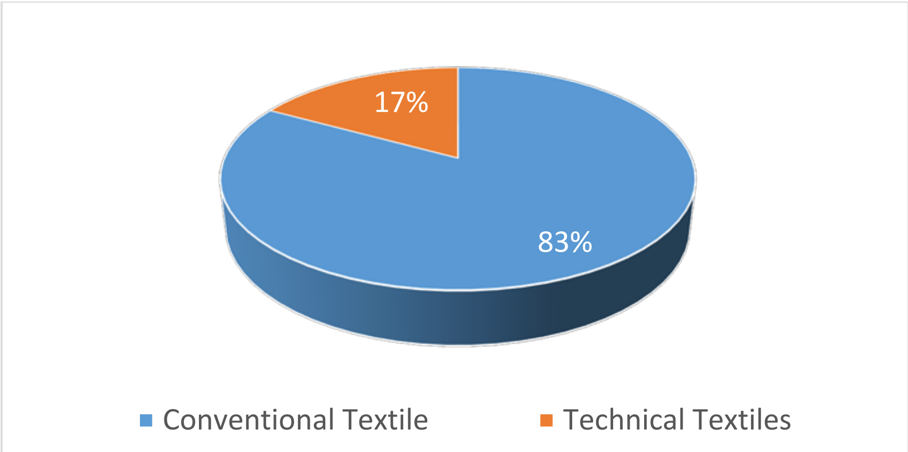


Fig. 2.3 Technical textiles v/s conventional textiles in Indian market (2019-20)

Fig. 2.4 displays the share of various types of technical textiles: Indutech, Mobiltech, Packtech, and Hometech collectively account for about 70% of the market [15].

Fig. 2.5 shows the worldwide consumption of natural and manufactured fibres in manufacture of technical textiles. The synthetic fibres polyester and polyolefin are mainly utilised in the production of technical textiles owing to their outstanding mechanical characteristics.

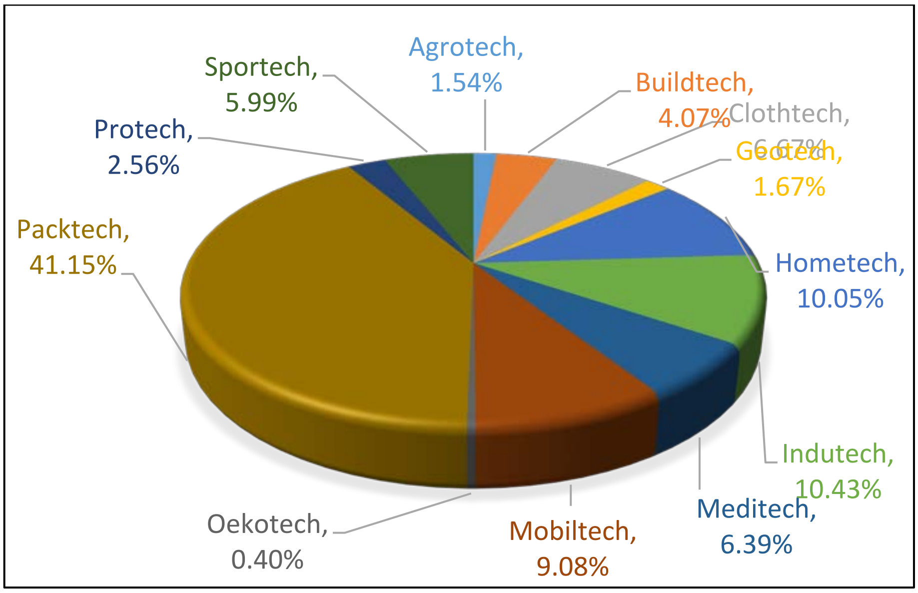


Fig. 2.4 Indian technical textile market (2019-20)

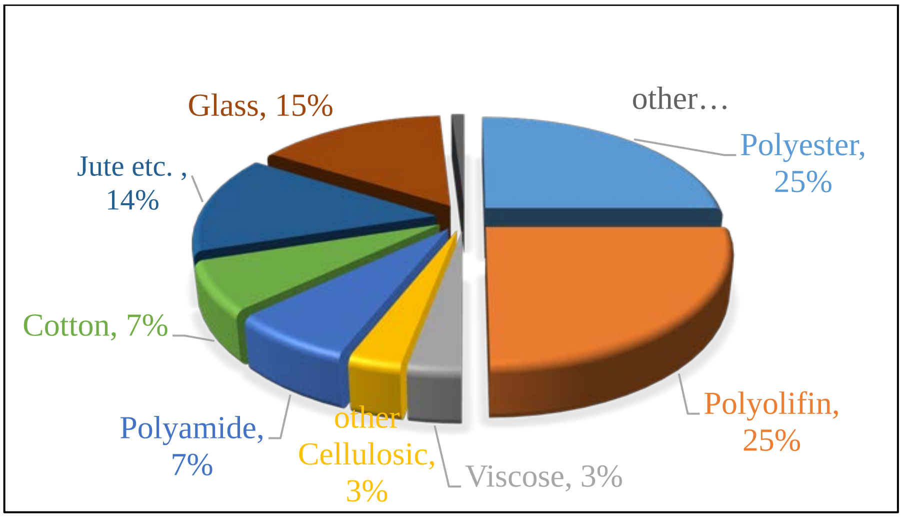


Fig. 2.5 World fibre consumption of various fibres in technical textiles

2.1.2 High Functional Fibres used in Technical Textiles

The main direction in the high function fibre development is to utilize biomimetics, i.e. to copy high order structure fibres like cotton wool and silk. Efforts have been focused on enriching human life by pursuing high function, aesthetic appreciation and human sensitivity. Such fibre is being applied not only to clothing but also in industrial applications. For industrial use, molecular design gives polymer raw materials a second-order function that can include mechanical, physical, chemical, and biological properties of the fibre. Fig. 2.6 displays these four character classes of high functional fibres:

- Mechanical features and characteristics
- Chemical features and characteristics
- Physical features and characteristics
- Biological features and characteristics

The mechanical category of fibres has characteristics like tensile strength, pressure relaxation generated by bulkiness, resistance to abrasion, and flexibility. These functions are generated

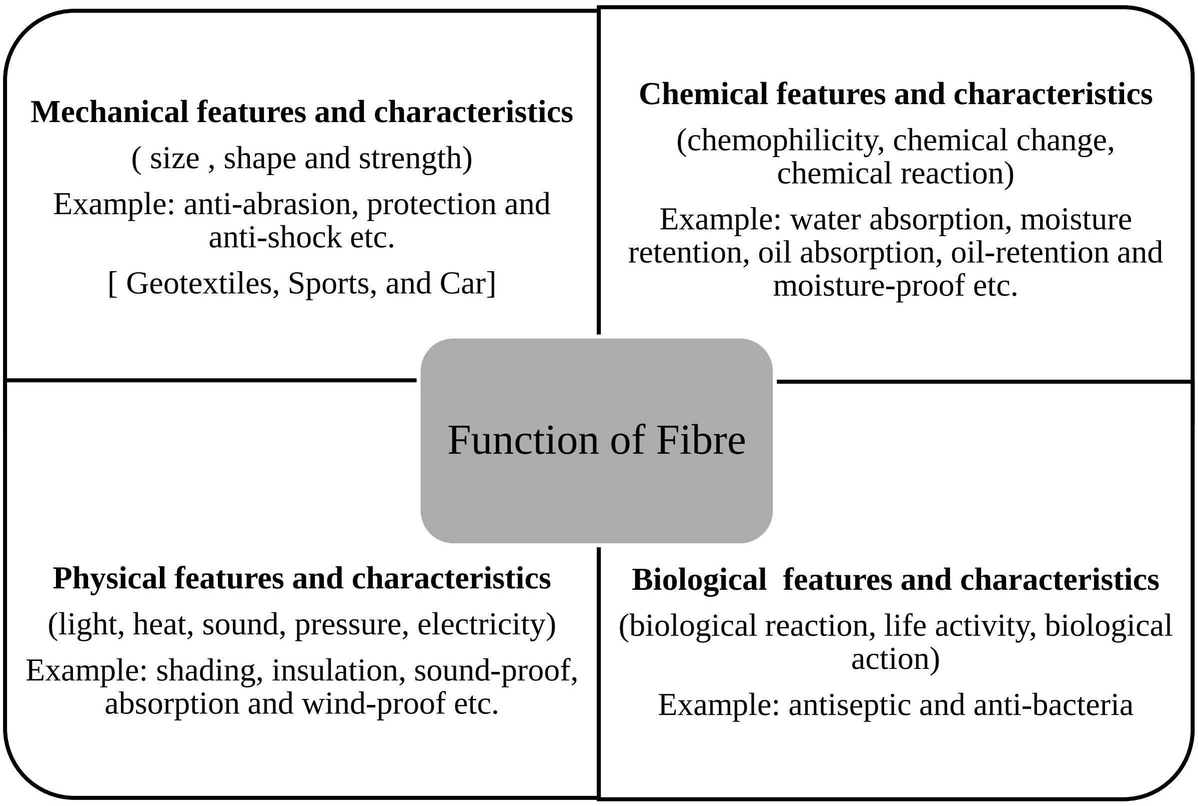


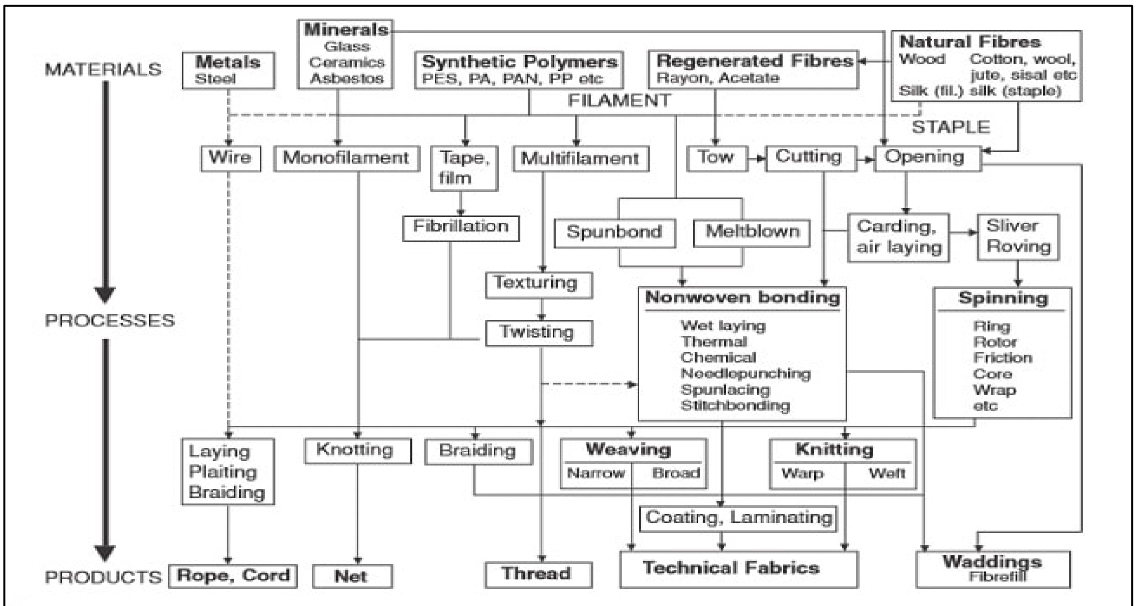
Fig. 2.6 Classification of high functional fibres based on their characteristics

through the process of aligning and crystallising chains along the fibre axis. Fibres belonging to the chemical class have similar characteristics to natural fibres, including their ability to absorb moisture. This property enhances the comfort level of clothes made from these fibres. The surface of these natural fibres contains densely packed functional groups in high quantities. Physical fibres possess characteristics like thermal resistance, moisture retention, anti-electrostatic qualities, and transparency. These fibres are used for thermal, electric, and light stimulation.

Fibres belonging to the biological class exhibit a notable illustration of the primary biological function, as evidenced by the fact that silk and wool possess a mild antibacterial effect. A fibre shape can purposely introduce a new function. Processing add a second-order clothing function for comfort. This class of high functional fibres are of the importance for the applications in the various medical textiles

2.1.3 Technical Textiles Manufacture

The conventional textile machines and processes are mainly used in the manufacture of most technical textiles. Fig. 2.7 shows the details of manufacturing processes for the various technical textiles. Many procedures and products are similar to those of conventional textiles. However the conventional textile industry rarely processed certain products such as metallic wires into cables, screens, meshes, or tyre carcasses.



Technical textile materials, processes and products. PES = polyester, PA = polyamide, PAN = polyacrylonitrile.

Fig. 2.7 Schematic diagram of manufacturing processes of various technical textiles

The mainly woven, knitted, braided and nonwoven fabrics are manufactured as technical textiles. However certain speciality processes are also used such as knotting, braiding, wadding etc. The wide range of raw materials including natural fibres, regenerated fibres, synthetic fibres, mineral fibres and metallic fibres, either staple or filament, monofilament or multifilament, split or fibrillated films, and extruded polymers also processed in to wide range of products. The certain applications of technical textiles are in filament fibre form or fibre fill form.

Fig. 2.8 shows the consumption of various Meditech products based in India depending on the cost of these products in the year 2019–20. The surgical dressings segment accounted the highest share of 30% followed by surgical sutures which accounts 27%, however compression garments and sanitary napkins have marginal share of only 2.7% and 3.2% respectively. The use of suture is of utmost importance the kind of the application in which is it is required to perform hence it is high in price. On the other hand consumption of sanitary napkins by weight is very high but its share in the market is nominal. The kind of its application is such that consumption is high due to its need is too frequent and more bulk requirements for every time it is used. Hence affordability plays important role in its market share in the overall medical textiles market.

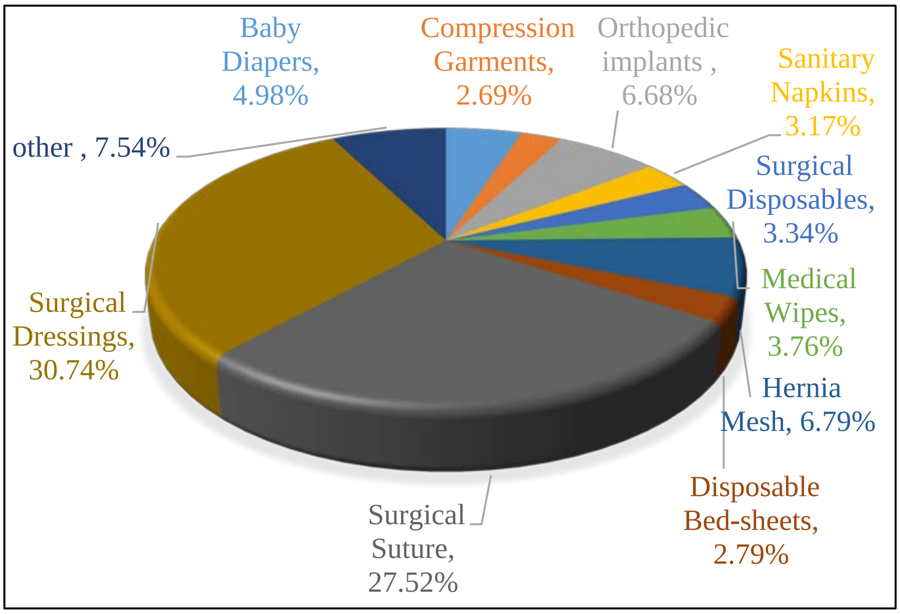


Fig. 2.8 Consumption of various medical textiles in India (2019-20)

2.2 Medical Textiles

Medical Textiles are the type of technical textiles which offer a variety of technical and functional properties having application in the field of medical and clinical care. The very main objective is to improve quality of health care delivery through disposable products and enhance the standard in health care delivery by minimizing the risk of infections.

Requirement for high level of medical treatment and higher quality of life has been increasing the importance of applications of textiles to medical uses. In addition, medical science based on biology is now rapidly progressing. Therefore, there is still a big space where fibre and textile technologies in this field can further be effectively utilized. The largest use of textiles is for hygiene applications such as wipes, babies' diapers (nappies) and adult sanitary and incontinence products. The other side of medical textiles market is a rather smaller but high value market for medical and surgical products such as operating gowns and drapes, sterilised packs, dressings, sutures and orthopaedic pads. At the highest value end of this segment are relatively tiny volumes of extremely sophisticated textiles for uses such as artificial ligaments, veins and arteries, skin replacement, hollow fibres for dialysis machines and so on.

2.2.1 Types of Medical Textiles

Healthcare is a serious business which is not only influenced by practicing medical professionals but also by the manufacturers of diverse medical products. In today's healthcare environment, textile products are finding innovative applications which were not imaginable just a few years ago. The importance of textile materials in the medical field is credited to their excellent physical properties, such as strength, extensibility, flexibility, suppleness, air and moisture permeability and wicking. Medical textiles and healthcare goods can be used for number of end use applications such as simple bandages to antibacterial wound care, biocompatible implants, tissues, prosthetics etc. Based on the application various medical textiles are classified in to four groups (Fig. 2.9) [16].

- Healthcare and Hygiene products viz. sanitary napkins, diapers, blankets, caps, masks, cloths/wipes
- Extracorporeal devices viz. artificial kidney, artificial liver
- Implantable material viz. sutures, vascular grafts, artificial ligaments
- Non-implantable materials viz. compression bandages, orthopaedic bandages

(a) **Healthcare and Hygiene Products:** The healthcare and hygiene business is a major textile usage in medicine. These are primary healthcare products meant for protection, general health care and hygiene, including bedding and clothing, mattress covers, surgical gowns, face masks, head and shoe covers, apparel, sterilization wraps, incontinence care pads, nappies, tampons etc. Advancements in textile technology and medical procedures have led to the development of various washable or disposable healthcare and hygiene goods as illustrated in Table 2.1. These products include Surgery gowns, Headgear, Masks, Patient drapes, Cover cloths, Barrier material, Bags, and Pressure garments.

All fibres utilised in this product must possess the qualities of being non-toxic, non-allergenic, noncarcinogenic, and capable of undergoing sterilisation without seeing a change in their physical or chemical characteristics. The available range of these products is broad, and they are frequently used in the operating room, theatre, or hospital ward in order to guarantee the hygiene, care, and safety of both staff and patients. [17].

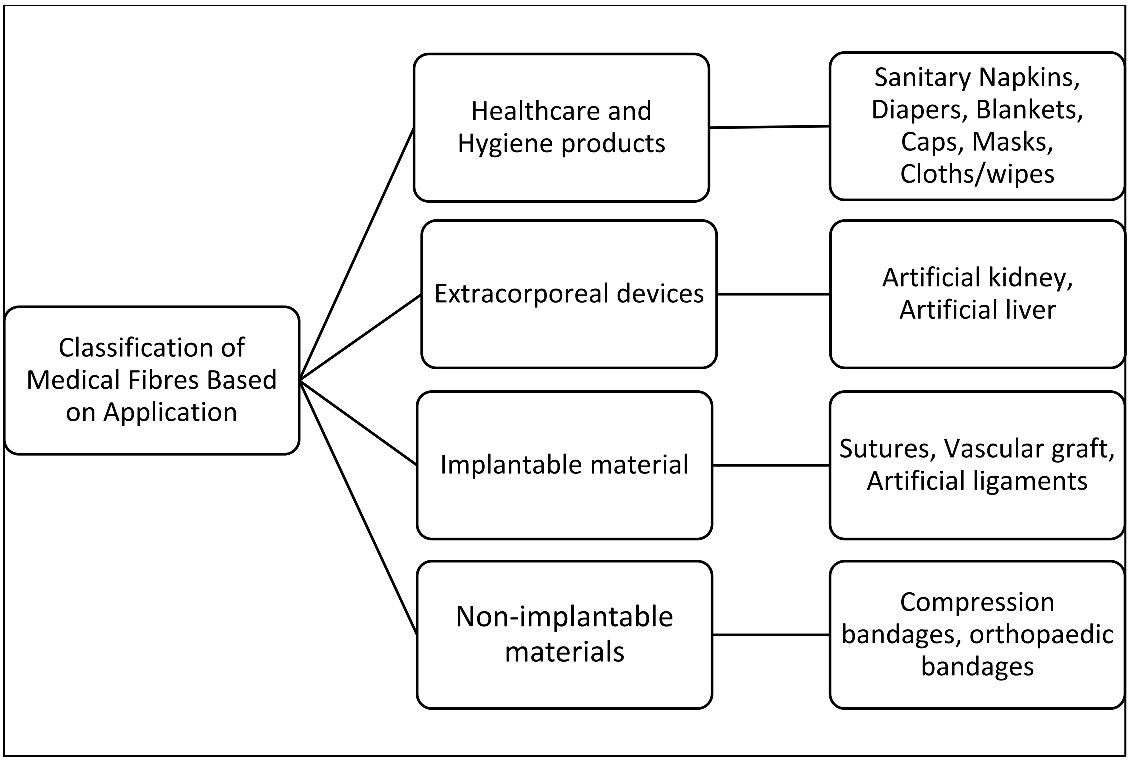


Fig. 2.9 Classification of medical textiles based on application

Table 2.1 Various healthcare and hygiene products

Fibre type	Fabric type	End-use product
Cotton, Polyester	Woven, Knitted	Beddings, Pillow covers, blankets
Cotton, Polyester, Polypropylene,Viscose rayon	Woven, Nonwoven	Surgical clotting, Gowns
Viscose rayon, Glass Polypropylene	Nonwoven	Caps, Masks
Polyester, Polyethylene	Woven, Nonwoven	Surgical cover, Drapes cloth
Polyester, Cotton, Polypropylene	Woven, Nonwoven	Protective clothing
Polyethylene, Polyester, Polypropylene	Nonwoven	Incontinence diapers sheet, Absorbent layer, Outer layer
Elastomers	Nonwoven, Knitted	Surgical hosiery

(b) Extracorporeal Devices: these are extra corporeally mounted devices used to support the function of vital organs, such as kidney, liver, lung, heart-pacer etc. The devices are mounted outside the body are used to keep important organs like the liver, kidneys and lungs working. Artificial organs like artificial livers, artificial kidneys (dialyzers), and mechanical lungs are used to clean the blood and supplement the air supply as the case may be **[**18**].** The fabrication of these devices requires careful design and production. These devices must be hypoallergenic, non-carcinogenic, resistant to microorganisms, antibacterial, non-toxic, and capable of being sterilised

(c) Implantable Material: These are materials implanted on or in the human body to either support or replace the functions of internal organs. Besides classical implantable textile materials, such as sutures, recent developments in the medical treatments have found new applications, such as heart valves, vascular grafts, artificial veins, artificial tendons and ligaments, artificial joints and bones, artificial skin, artificial cartilage etc. Other products are tissue scaffolds and sutures, composed of single or multiple filament threads, heal wounds, halt bleeding, and repair soft and hard tissues. In ophthalmology and dentistry, they cure wounds and burns and are utilised as biomaterials for prosthetic ligaments, joints, heart valves, vascular grafts, veins, and skin [19, 20].

(d) Non-implantable Materials: Non-implantable medical textiles are materials that are used externally on the body to help in the recovery of injuries. Non-implantable goods are commonly utilised for the purpose of preventing infection, absorbing blood, exudates, and facilitating the healing process. The phrase non-implantable is commonly employed to refer to surface wound treatments for various regions of the human body. Non-implantable materials used are wipes, swabs, wound dressings, bandages, gauzes, plasters, pressure garments, orthopaedic belts, etc.

2.2.2 Various Structures of Medical Textiles

The characteristics of a fabric generally depend on the fibres, yarns and the fabric's structure. The conventional manufacture processes have been used for the most medical textiles such as woven, knitted, braided, or non-woven. However some medical applications require specific structure hence speciality processes are used for example lamination or coating for the waterproof fabrics. The modified spun-bond nonwoven process (SMS) is used for efficient filtration in case of medical masks to retain virus. In case of some applications polymer films, composites, 3D braids are also manufactured to meet the specific requirements (Fig 2.10).

(a) **Woven Fabric**: Woven fabrics can be regarded as sturdy constructions with lower stratchability and porosity compared to other textile structures. The constraint of woven fabrics arises from their inclination to unravel at the edges when cut into square or oblique shapes for the purpose of implantation. The emergence of the leno weave in the production of textile structures has offered a solution to the issue of fraying. Woven textiles such as bandages, vascular plugs, vascular grafts, tissue scaffolds, and artificial ligaments are commonly employed in the medical profession. The applications encompass vascular plugs, vascular grafts, tissue scaffolds, artificial ligaments, and more.

(b) **Knitted Fabric**: Both weft knitted and warp knitted fabrics are used as depending on the functional requirements. Although weft knitting structures can be stretched quite a bit, they can become unstable in terms of their dimensions until more interlocking yarns are added. Adding these extra yarns makes the elastic rebound better. It is possible for warp knitted structures to have dynamic properties better than those of woven. The knitted structures are more porous. These are suitable for surgical meshes, shields against adhesion etc.

(c) **Braided Textiles:** Cords and stitches have been made with braided structures, which can have different designs including hollow. These structures are highly porous . This means that fluids can pass through the spaces between the yarns or strands in the braided structure. Changing the capillarity of the braided structures can be done by covering them with Teflon or treating them with polylactic acid. These coats help to improve the properties of braided structures and lower noise levels when the body moves. When the surgeon presses down with his finger, these treatments also help line up the knots in the stitch. This structure is suitable in tubes, sutures, and other such medical tools.

(d) **Nonwoven Fabric: N**onwoven textile structures are mainly dependent on the characteristics of the polymer or fibres used and the bonding method used for the manufacture. Polypropylene is an example of a polymer that is used in medical textiles because it doesn't absorb water and can grow in a micro-structure. The nonwovens made from polyurethane look like collagenous materials and are used in medical textiles. Many things can be used, like diapers, sanitary pads, surgical gowns, surgical caps, and more.

The future trajectory of fibre technology for medical textiles and other applications will be significantly influenced by evolving needs of the society. Additionally, it entails developing novel products to address emerging needs in the expanding fibre industry. Speciality fibre features include precision-engineering fibre materials for surgery and intervention. Infection control, wound therapy, and life-saving risk management are specialty fibre features. These can be addressed by using proper fibre type and suitable textile structure.

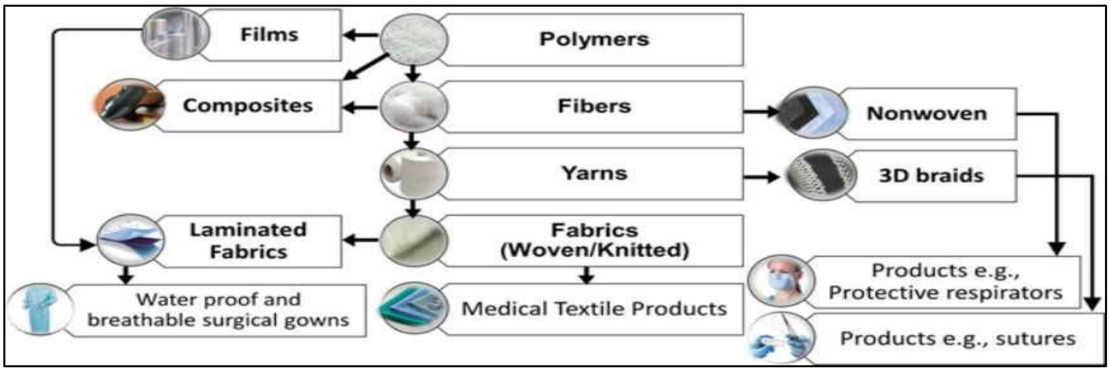


Fig. 2.10 Schematic diagram showing various processes of manufacture of medical textiles

2.2.3 Basic Criteria of Medical Textiles

The textile fibres utilised in medical applications should possess distinct qualities that are expected to performance satisfactory. The global fibre consumption in medical textiles is increasing with increase in population [21, 22]. Both natural fibres and synthetic fibres have applications in the medical sector, each possessing distinct features and functions that contribute to advancements in medical practices. The textile materials have to possess some features in terms of their properties to be utilized as bio-medical products. For safe and effective use of textiles in medicine and surgery it is necessary to meet with a number of general and specific criteria such as:

- Acceptable compositional purity and free from any surface contaminants.
- Good dimensional stability and ability to retain crimping
- High elasticity and elastic recovery.
- Non toxicity, non carcinogenicity and non allergenacity
- Flame proof and waterproof under wet conditions, if required.
- Dyes used must be fast and non-irritant.

Materials should be sterilizable with minimum change in chemical and physical properties. The type of sterilization technique being used depends upon fiber characteristics. Depending on end use application, medical textiles should be capable of sanitization. In certain cases, bio-chemical properties such as bio-degradability, bio-compatibility, non-harmfulness etc. are required. One of the important properties required is absorbency governed by structural element and being improved by addition of absorbent co-polymers during manufacturing. Most medical textiles should have sufficient strength, softness, flexibility and stability [23].

Wound healing happens in four continuous phases: homeostasis, inflammation, granulation tissue formation, and remodelling. Due to their increased surface area, porosity, and air and moisture permeability, textile-based structures aid wound healing. These structures are strong, elastic, and flexible enough to be reinforced with healing chemicals. Charcoal cloth, chitosan, xerogels, hydrogels, and alginates are polysaccharide-based wound dressings that prevent bacteria, provide occlusion, elasticity, and fluid balance. Hydrogel wound dressings keep the wound surface wet and reduce necrotic tissue build up, speeding wound healing.

2.2.4 Fibres for Medical Textiles

Textile fibres are the main raw materials used as building blocks of medical fabrics. Both natural and man-made fibres can be spun into yarn, which can then be knitted or woven using specific interlacing techniques, or bonded into nonwoven fabrics like felts or films [23]. Natural fibres such as cotton, silk, linen, regenerated fibres viscose, lyocell, and cellulose acetate, alginate have been used conventionally. Cellulose is the most common natural polymer. The two types of regenerated cellulose fibres used in medicine are rayon and lyocell; cellulose acetate and carboxymethyl cellulose are derivatives.

Manufactured fibres Polyester, Polypropylene, Polyamides, Polyethylene, Silicon, Poly-methyl-methacrylatee, Polylactide, Polyglycolide, Polyurethane, carbon, glass etc. are recently added to the list. These polymers have at the molecular level, polymeric chains arrange into crystalline and amorphous segments, moreover its fibrils are long crystalline structures which are useful features to impart necessary properties [24].

Alginate, have been used in medicine because they have special properties like being able to dissolve in water, being able to take a lot of fluid, breaking down naturally, and being compatible with living cells. The fibres can be chemically modified to enhance the properties. For example, a viscose fibre that absorbs water can be made hydrophobic, and a polypropylene fibre can be made hydrophilic. In many situations blending of fibres strands is necessary to achieve the best results. Fig. 2.11 shows various fibres for medical applications grouped base on its source viz. natural origin, synthetic polymer and natural polymer [**25**].

(a) Natural Origin: Natural fibres are widely used and because they have a unique molecular structure that creates a bioactive matrix that makes them biocompatible and biodegradable. Natural fibre nanostructures are complex and organised in motifs, whereas synthetic fibres lack multilayer structure. The tensile strength, hardness, and modulus of flexibility of a natural fibre can’t be engineered unlike synthetic fibres. The polymerisation which happen naturally in natural fibres aren't usually important for connecting with cells in the blood and organs, cell receptors, and proteins. The modifications are now being looked at to make them better [26]. Medical uses of natural fibres date back to ancient times.

- **Cotton:** Cotton fibre is soft, cool, and comfortable having fibrillary structures, porous sponge and fine capillary system. As a result, the cotton is able to wick and absorb water in a special way. Owing to its good handle, soft drape, and absorbency, cotton is used in uniforms for hospital personnel, pillow covers, bedsheets, surgical gowns, hosiery, gauze, wadding, tampons, bandages, and absorbent swabs that are not implantable in medical and surgery settings [27].

- **Silk:** is used to construct imitation tendons, ligaments, and shock padding. Silk is more biocompatible and mechanically superior. Electro spun silk fibres can create 2D and 3D

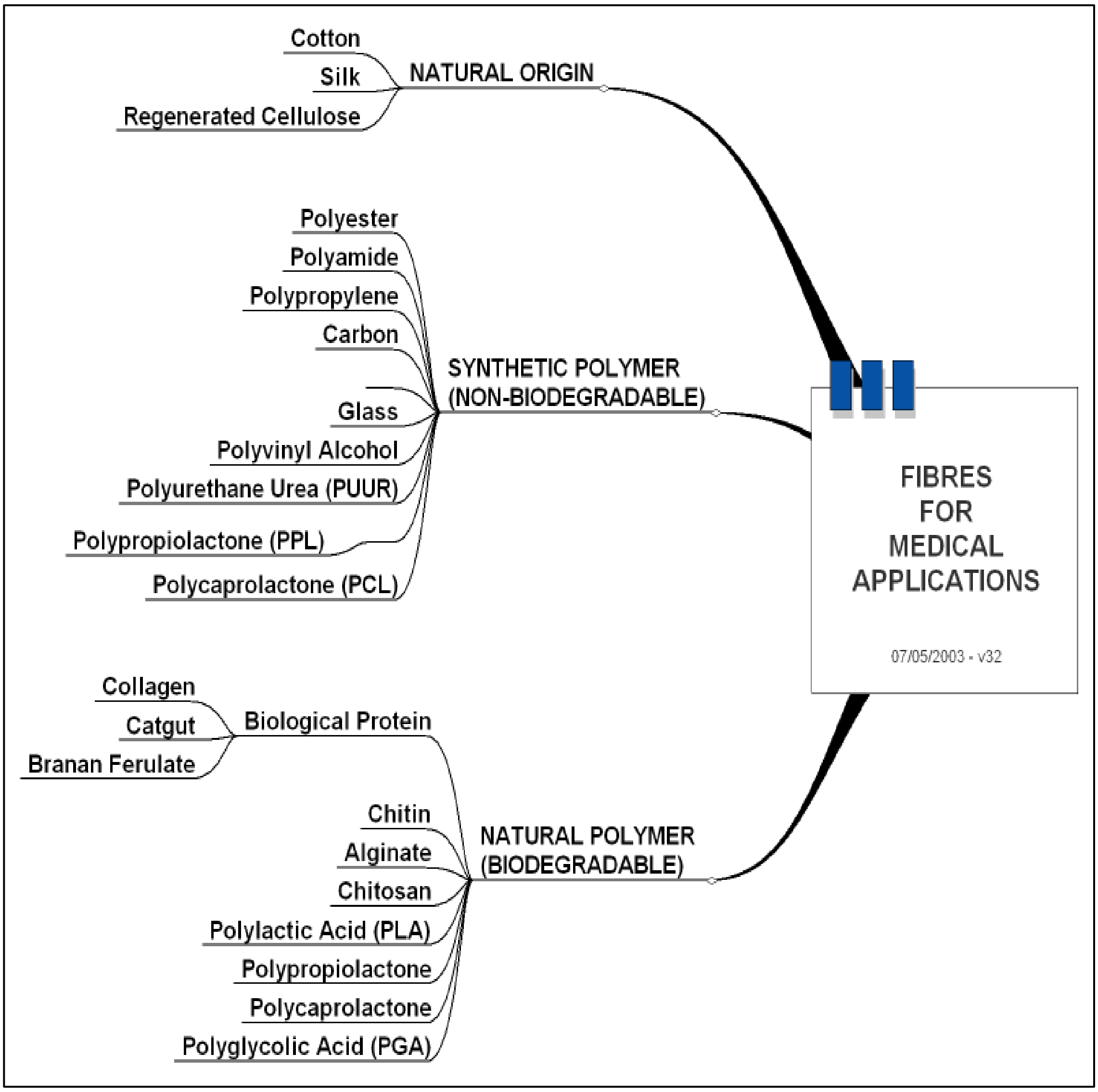


Fig. 2.11 Classification of fibres for medical applications

matrices that may help repair and generate new tissues [28]. Silk 3D fabric with polymer gel, possibly alginate, could create biomechanically stable material. As it breaks down, silk fabric produces actual cartilage on top, and the hole heals without implants. Spider silk is composed solely of proteins, have good biocompatibility, used in various hydrolysis products. As silk can break down amino acids into harmless products, it is a great choice for making a bioresorbable cloth scaffold [29].

- **Bamboo and Soybean Fibres:** Bamboo fibres are intrinsically antibacterial, softer and more absorbent than cotton, biologically degradable. The antibacterial capacity of bamboo fibres is attributed to the presence of an exceptional antibacterial and bacteriostatic bioagent called bamboo Kun. Because of its sterilisation property through bacterial growth inhibition and bacteriostasis, it is use in home furnishings, apparel, and hygiene products. The use of 100% bamboo fibres in surgical wear hinders bacterial growth. Soybean fibre is also a regenerated fibre with good physical properties that are good for human health. Both bamboo and soybean fibres have been used as an alternative to classic medical bandages, and in baby diapers.

- **Viscose Rayon:** The fibre absorbs moisture more quickly and has a moderate degree of strength. Rayon fibres expand in water and burn quickly if untreated. These fibres are used to produce medical textile items such as caps, surgical gowns, masks, absorbent pads, wadding, plaster, and basic bandages and wipes. Knitted viscose dressings and gauzes are suitable as the main non-sticky or anti-sticking dressings for treating highly oozing lesions, such as leg ulcers.

- **Lyocell:** The lyocell or hydrocele could replace alginate calcium, which is used to make the best patches for burns and wounds. It supplements antibacterial medicines, and creates a moist environment that helps wounds heal quickly. Additionally, hydrocele is better at absorbing water, 35 times its own weight, than alginate fibre. This means that the patch is easy to put on and easy to take off.

- **Cellulose Acetate:** This fibre is made up of the acetate ester of cellulose having unique properties. The acetate fibre undergoes decomposition in response to the strong and concentrated acid exposure. Also, the strong alkalis and longer sunlight exposure damage this fibre and cause weakening effects. Cellulose-acetate nonwoven fabrics have been successfully employed for the controlled release of vitamins and to provide mesh for wound dressings. Cellulose-acetate hollow fibres have also been exploited for hem purification and in the assembly of liver-assisted bioreactors [30].

- **Carboxymethyl Cellulose:** The Carboxymethyl cellulose (CMC) is extensively applied in the medical field because of several corresponding properties; these include high water absorption, biocompatibility and biodegradability. It has been used in the forms of powder, films and gel. The nonwoven made by CMC has been used as a wound dressing.

(b) Synthetic Polymer: Man-made synthetic fibres are widely used in medical textiles and healthcare [31, 32]. With increase in demand, natural resources are scarce, innovative technology is more important to develop biomaterials for this requirement. As compared to natural fibres, synthetic fibres are cheaper, stronger, easier to wash, and easier to maintain, waterproof and stain-resistant, colour, electrical conductivity, chemical composition, lustre, moisture absorption, flexibility, and microscopic appearance [33]. In addition to their chemical and physical features, polymers have some functional properties. Semipermeable polymer or biopolymer membranes like cellulose are used for medication delivery or hemolysis. Drug release in vivo occurs when membrane pores collapse or swell in response to temperature, pH, and other stimuli. Orthopaedic support materials that protect and support joints are a major medical textile use. These applications include back, shoulder, elbow, ankle, wrist, and knee supports. TENS therapy garments are made using spandex.

- **Polyesters:** The most versatile thermoplastic synthetic textile fibre, polyethylene terephthalate (PET) is used in wide range of products such as gowns, masks, surgical covers, drapes, beds, protective cloth, surgical hosiery, blankets, and cover stock. Braided polyester filaments are used to make artificial tendons, arteries, heart valves, prostheses, grafts, surgical sutures, and ligaments. Multi-braided polyethylene terephthalate polyester makes up the Proflex ligament [34]. A knitted PET vascular prosthesis is a common graft for 6 mm and larger arterial arteries. Dressings and plasters use PET fibrous structures, while artificial kidneys use PET hollow fibres. Two-stage modified polyester fibres are highly antibacterial. Spacer fabrics for thermal and tactile comfort use two engineered polyester fibres with better moisture wicking four-channel

Dacron and micro-denier polyester combined with cotton. Poly-4-hydroxybutyrate (PHB) is another new polyester fibre with absorbable characteristics and implantable medicinal applications. It's robust, flexible, and can disintegrate in vivo through surface erosion. PHB is clinically used for in vivo surgical patching. Semi-crystalline polyester, polycaprolactone (PCL) due to its low degradation rate, is used for long-term, regulated medication administration. PCL-poly (ethylene oxide) electrospun nonwoven membrane can be used to control the release of proteins.

- **Polyamides:** Polyamide fibre is suitable for making the surgical hosiery, surgical sutures, artificial ligaments, tendon, lumen, absorbent pads, and basic bandages. Medical wound dressings utilize nylon. Medical professionals use flexible silicone-coated nylon mesh as a soft, porous, anti-adherent wound dressing [35].
- **Polyolefin fibres:** Polypropylene (PP) fibres are used for cleanliness, non-absorbable sutures, surgical gowns, and protective garments. In diapers, PP nonwoven layer is the distribution layer, while spun-laced PP and viscose rayon nonwoven sheets are wipes. PP hollow fibres are used in mechanical lungs. Prostheses, plasters, and partially degradable implantable meshes with 50% polyglycolic acid use PP fibres. Polyethylene (PE) is used to make surgical drapes, covers, sandwich multicomponent dressings and as sanitary napkin top sheets. PE mesh can be used to create artificial bones and ligaments. PE fibres support drug-delivering ion exchange fibres [36].

- **Polyvinyl alcohol:** A water-soluble polyhydroxy synthetic polymer, polyvinyl alcohol (PVA), has strong strength, flexibility, emulsifying, film-forming, water solubility, and adhesive capabilities. Chemically and biologically resistant, PVA has strong oxygen and aroma barriers. Its water-soluble characteristic makes it a useful biomedical raw material for wound dressings and hydrogels. PVA may be easily crosslinked with other biopolymers to improve mechanical characteristics and minimise water solubility. Silver nanoparticle-infused PVA fibre hydrogel wound dressing is antimicrobial [37]. Composite electrospun fibrous membranes of poly (ethylene oxide)/poly (vinyl pyrrolidone)-iodine complex can also make antimicrobial wound dressings [38].

- **Acrylic Fibres:** Acrylic fibres are used to make cohesive dressings and bandages and also utilised in hygiene products due of its absorbency. Crosslinked polymerized acrylic acid creates super absorbent fibres due to their unique structure and size. Small diameter irregularly wavy or serrate fibres with longitudinal grooves provide a high surface area for moisture absorption even under pressure. [39].

- **Polyurethanes:** Elastic polyurethane filaments spandex is used for surgical hosiery and elastic stockings for compression therapy. Processing polyurethane filaments requires specialised equipment for even and consistent compression. Electrospun polyurethane nanofiber membranes can scaffold cell development, wound treatment, and bandages, or be hydrophilic and hydrophobic. Abrasion, strength, and tissue compatibility characterise these fibres [40].

- **Sulphur and Silicon-Based Fibres:** Fluoro-bearing synthetic polymers, such as PVDF and PTFE, are often used in long-term medical implants and supports because of higher strength, biocompatibility. Medical-grade PVDF multifilament yarn is used to make sutures, ligaments, herniameshes, vascular grafts, and prosthetic corneas. PVDF warp-knitted fabrics have been used to build hollow body prostheses, including suture less aortic valve prostheses and blood-tight elastic textile structures. PTFE is suitable for coating medical devices due to its strength, hydrophobicity, chemical stability, and low coefficient of friction. Vascular prostheses, grafts, cardiovascular implants, heart valves, artificial ligaments, filtration membranes, sutures, artificial ligaments, tendons, and lumens have been made using PTFE fibrous structures. Orthopaedic implants, prosthetic joints, bones, and non-adherent dressings utilize silicone. A bioreactor for hemolysis and prosthetic kidneys uses olyethersulfone hollow fibres and membranes.

- **Inorganic Fibres:** Among the various inorganic fibres, glass and carbon have been used in medical textiles such as caps, surgical masks, artificial bones, and joints. Medical diagnostic and sensing technologies use the optical fibres of a typical glass. Carbon fibres are biocompatible and strong, have been used to replace anterior cruciate ligaments and tendons. Orthopaedic implants, joints, and bones made of carbon fibre-reinforced PEEK plastic have also proved successful. The wound management dressing also has an activated carbon fabric layer to prevent odour.

(c) Natural Polymer (polysaccharide based fibre)

- **Alginate:** The alginate has been extruded from brown seaweed algae and is a natural hydrocolloid polysaccharide that gels to make fibres. In a simple wet spinning method, sodium alginate-doped fluid is coagulated in a calcium chloride bath to extrude fibres. Alginate nonwoven dressings provide many advantages over traditional dressings, especially for wet wound care. Alginates' gelling characteristics aid wound care and fibre extrusion. Calcium alginate wound dressing absorbs moisture and exchanges sodium with bodily serum. Swelling and hydrogel production at the wound surface impede lateral infection. In wound treatment, alginate's gel-blocking, fluid management, pain control, healing, and hemostatic qualities are useful. Alginate primary dressings work well for cavities and medium-to-heavy leaking wounds, but not dry wounds. A typical alginate membrane comprises 90% open space and has been used as a scaffold.

- **Chitosan:** Chitin threads obtained from fngi and crab shells used to make good wound dressings which help wounds heal faster. Chitosan, which is the deacetylated form of chitin, can kill germs; stop bleeding, help wounds heal. One of the best plastics, chitosan, can fight tumours and is safe for living cells. It can break down naturally and works better for treating burns wounds, because it releases glucose, which speeds up tissue formation and supports homeostasis.

  Suture materials are usually covered with silicon, whereas chitosan coating prevents inflammation, scarring, and microbes. There are several things that make chitosan antimicrobial, but it kills algae and fungus better than bacteria. Fibres made of chitosan have also been used to make tampons, supports for tissue engineering, and drug delivery systems. Hydrogel and nonwoven dressings made of carboxymethyl chitosan improve absorption and wound healing for chronic ulcerative lesions. Cyanoethyl chitosan has also been utilized as a wound dressing due to its antibacterial properties.

- **Alchite:** Gel-forming alginate e-wound treatments break down and become less strong. Patients cannot remove the dressing in a single piece at multiple events. This leads to the creation of strengthened wound dressings with gelling and non-gelling materials that firm up on soaking and make removal easy. The development of alchite fibres made of combining two polysaccharides alginate and chitosan creates a conjugate with unique mechanical and physical properties that differ from individual chitosan and alginate fibres. On the other hand, the surface of alchite fibres is rough, like wool, while the surface of alginate fibres is smooth and plain.

- **Hyaluronan:** Hyaluronan, or hyaluronic acid (HA), is another naturally occurring linear anionic polysaccharide comprised of repeating disaccharide units of Nacetyl-D Glucosamine residues. It can be recovered from biological sources such as rooster comb, umbilical cord, and bovine vitreous. It is a water-soluble polymer and provides viscous solutions. It is also an ideal candidate for wound healing applications because it can interact with biomolecules, bacteriostats, and scavenging free radicals at wound sites. Hyaluronan has also made an impact as a biomaterial scaffold in tissue engineering.

- **Polylactic-acid:** Polylactic acid (PLA), also known as polyglycolic acid (PGA), is linear aliphatic thermoplastic polyester that comes from plants. Some biomedical uses involve wet-spun PLA fibres. PLA was initially used in drug delivery systems and stitches because it was cheap and easy to get. Growing body parts on PLA textiles, living cells from human organs are grown and cultured on a textile scaffold to achieve 2D and 3D morphologies. Fibrous connective tissues replace the implant as it breaks down naturally in the body without injury, so they don't need surgery again.

  Poly electrospun nanofiber scaffolds contain a water-soluble antibiotic to control released body fluid etc. PLA provides absorbable surgical sutures scaffolds for skin grafts, implants, and prosthetics in bone tissue engineering. These repair and develop bone and cartilage. Nerve guides made of PGA can be tubed. PLGA is used to make micro and nanoparticles, grafts, implants, sutures, and prosthetic devices.

- **Collagen:** Many human and animal tissues contain collagen, an essential protein. It's crucial to non-implantable and implantable materials' structures. Interactive wound dressings boost cell development and soft tissue repair with collagen fibres. The dressings can be made of native or electrospun collagen. Because of its many safe structures, collagen is interesting to investigate. Due to its unique biological, mechanical, and physiochemical properties and enzyme-breakdown capabilities, collagen has been extensively investigated. Ancient people were bound with collagen. Tubular, resorbable nerve guides and scaffolds have been made from collagen fibres.

- **Gelatine:** The extraction of collagen for gelation often involves the use of diluted acid to recover it from animal skin and bones. Peptides chemically bond 19 distinct amino acids in gelatine. Furthermore, gelatine is effective in halting haemorrhaging. Gelatine hydrogel bandages are predominantly used for treating burns, severe wounds, sores, and ulcers. Furthermore, gelatine scaffolds have been utilized in tissue engineering to enhance the proliferation and migration of vascular cells.

2.2.5 Characteristics and Suitability for Medical Textiles

The suitable polymers are processed into fibres, yarns and textiles that possess the appropriate structures such as woven, nonwoven, knitted, braided etc. and to impart characteristics required for the particular application. The wide range of fibres are available such as from natural source viz. cotton, silk, viscose rayon etc. manufactured fibres viz. polyester, polyamide, polyethylene, polypropylene, glass, elastomer etc. Depending on the characteristics of fibre and requirements of end use application, wide ranges of medical textile products are available. Different chemical processes are also carried out on these textiles to impart particular characteristics (Table 2.2).

(a) Properties of Natural Fibres: Depending on source like plants, animals or minerals, natural fibres traits are very different. Cotton, flax, and hemp fibres are cellulosic, cotton has a twisted ribbon structure, flax and hemp has a polygonal cross section, wool exhibit crimps and scales, while silk is triangular cross section with round edges. Regardless of the chemicals, these morphologies and internal crystalline structure of each fibre determines their physical and mechanical qualities. The proteins in wool are structured in α-helices, while the proteins in silk are structured in β-pleated sheets. So, wool fibres are more flexible and higher stretch. Cellulose-based fibres are very good at resisting concentrated alkalis and cold concentrated acids, but they break down when they get too hot. Alkalis and strong acids do a lot of damage to protein-based fabrics like wool and silk. Fibres made from cellulose and protein can both be broken down by bacteria and light bur very good at reabsorbing moisture.

Table 2.2 Applications of different types of fibers in medical textile

Sr. No.	Type of fibre	Type of medical textiles
1	Cotton	Surgical gowns, Bedding, Pillow covers, sheets, Uniforms, Surgical hosiery
2	Viscose	Caps, Masks, Wipes
3	Polyester	Gowns, Masks, Surgical cover drapes, Blankets, Cover stock
4	Polyamide	Surgical hosiery
5	Polypropylene	Protective clothing
6	Polyethylene	Surgical covers, Drapes
7	Glass	Caps, Masks
8	Elastomer	Surgical hosiery

(b) Suitability of Natural Fibres: Cotton, a cellulose-based fibre, has long been used in wound dressings. Due to their moisture absorption and physiological comfort, they are ideal for hygiene and healthcare clothes. Medical textiles utilize these threads beyond implants. Protein-based natural fibres like wool and silk differ from cellulose fibres. Natural fibre provides a bioactive matrix for biocompatible and intelligent material design due to its robust molecular structure. Protein and cellulose nanostructures are complex and organised, making them difficult to change and reproduce [41].

Researchers are investigating ways to make wool and silk more antibacterial. Silk fibre sutures are used, although they are not as effective as other materials for closing tissues. Also used for bone healing. Microbicidal or antimicrobial fibres, whether natural or synthetic, are better for medical materials because they inhibit bacteria from sticking to other fibres. Healthcare textiles like bed linens and bedding shape the patient's microclimate through their temperature and tactile qualities. The cloth's thermal and tactile properties help dissipate body heat and allow perspiration water vapour to pass, making it soft and smooth.

(c) Applications of Natural Fibres in Medical Field: Traditionally people have utilized various plant and animal products such as wool, leaves, resin-treated fabric, honey, and eggs to heal wounds, control bleeding, relieve pain, absorb fluids, and protect new cells. Some of these treatments undoubtedly very effective for the cure. Researchers are now considering honey as an antibiotic to treat wounds due to its bacteria-destroying properties. Honey may help wounds heal by boosting monocyte cell inflammatory hormones, according to recent research. The doctors and other medical workers wear gowns and masks to protect them from risk of infection. Safety clothing designers follow the rigorous guidelines. Regular weave and circular knitted classical bandages should be composed of finely twisted yarn for painless removal. Thermal and tactile properties are vital for soft, smooth-surfaced therapeutic textiles. These fabrics were manufactured using "spacer fabric," face-to-face velour weaving. A pile of yarn sews two layers together. These textiles let more air through, handle dampness better, and relieve pressure better. Manufacturers can make spacer fabrics by using warp or weft knitting on a circle knitting machine with a double jersey or double insertion rapier. Transcutaneous electrical nerve stimulation (TENS) treats several painful diseases. Wearable TENS garments are a novel form of health care therapy. These smart textiles are near the skin and constructed of elastic materials; thus, pressure must be spread uniformly [42].

(d) **Properties of Man-made Fibres**: The benefits of synthetic fibres over natural fibres are that they have better stiffness, tensile strength, biodegradable, biocompatible, economical, and bio-system-friendly. These fibres absorb dyes well and are highly absorbent, stretchable, strain-resistant, waterproof, and resist sunshine, oils, acids, and alkalis. Moreover they rarely shrink and endure longer than natural fibres, dry quickly and require little ironing, and easy of processing. Despite these benefits, they have certain drawbacks like hydrophobicity, finishing difficulties, pilling, wearing discomfort etc. Moreover some fibres have very low melting temperatures hence melt easily. These fibres also are heat-sensitive, poorly insulated, and burn faster than natural fibres. Synthetic fibres absorb very little moisture and become sticky when sweating. Polyamide fibres retain a more microorganism-causing smell than natural fibres. Pathogenic bacteria develop on polyester and other synthetic fibres.

(e) **Biocompatibility of Man-made Fibres:** A biomaterial can be used to replace any organ, tissue, or physiological function for a longer period than medication and diet. These materials must be biocompatible to be used in the medical therapy.

Biocompatibility is the capacity of a biomaterial to perform the intended physiological activities without causing systemic or local side effects, and optimising the treatment's therapeutically applicable dosage and maximising tissue and cell benefits. Electrospinning offers a viable solution for the tissue engineering difficulties to produces fibrous scaffolds with high biodegradability and biocompatibility. Electrospun man-made fibres also enable scaffold tailoring. These compounds' in vivo absorbance depends on their chemical structure and crystalline degree. Antimicrobial fibres are the most effective in wound healing and chronic wound prevention to hinder bacterial and fungal growth and kill them.

(f) Properties of Regenerate Fibres: Regenerated specialty fibres suit medical needs for biocompatibility, antibacterial activity, bioabsorbency, and biocompatibility. These compounds restore skin cells faster than ordinary dressings used in controlled-architecture textile scaffolding and wound dressing frameworks. The hydrogel bandage is removed easily and painlessly.

Alginate nonwoven wound bandages can retain exudate and gel-blocking phenomena, making them better than standard dressings. These scaffolding materials are bioresorbable, so only tissue remains on the implant site. These materials' structural stability is an issue. Due to its many particles, alginate dressing is difficult to remove, especially from cavities. Making stronger or more flexible wound dressings can be resolved this problem.

(g) Biocompatibility of Regenerated Fibres: Regenerated fibres have fibrous structures which exhibit distinct characteristics such as lack of cytotoxicity and allergenicity, biocompatibility, bioactivity, selectivity, absorbency, bioabsorbability, and biodegradability to exactly meet the requirements of the medical field. These materials don't have enough tenacity, elasticity, longevity, or long duration biostability. Hence find frequent application in scaffolds, sutures, wound dressings, and drug delivery systems.

Researchers have used genetically modified elastin to repair cartilage tissue. Because they can interact with molecules, carbohydrate-based wound dressings, such as alginates, charcoal cloth, hydrogels, and chitosan useful to cure burns and chronic wounds, such as being easy to put on and take off, absorbing, blocking, and maintaining fluid balance. In dermatology, collagen is primarily used to heal wounds and promote tissue growth. They can also be used to make reinforced or composite fibrous structures.

(h) Use of Regenerated Fibres: Viscose and Tencel, cellulose-based regenerated fibres, absorb moisture well and adhere poorly to heavy-exuding wounds. Interactive wound dressings may use collagen and gelatine. Ulcer, infection, and wound tissue colour determine the selection of dressing to be used.

New technologies is tissue engineering include tissue-inducing chemicals, cell replacements, and cell insertion on or in matrices. The later, using cells and scaffold materials as biological substrates to treat organ dysfunction or loss. Cells implanted into the scaffold grow and multiply in three dimensions, enabling the creation of new tissues with the desired shape and functions. Materials for nano fibre scaffolds include collagen, chitosan, alginate, polylactic, and polyglycolic acids. Electrospun nanofibers consisting of regenerated polymers were used in nanocomposites for drug delivery, scaffolding, and medicinal applications. By providing mechanical support for lumen restoration and fluid flow, stents help relieve intestinal blockage and stenosis. Due to its biocompatibility, biodegradability, absorption rate, elasticity, and flexibility, in case of polydioxanone stents another surgery is not required for removal. Weft knitting and braiding is used to construct the stents, often made from biodegradable aliphatic polyesters such as poly (lactic-co-glycolic acid) and polylactic acid.

Asahi chemical co. has developed a hollow cellulose fibre membrance (Bemberg microspores membrance (BMM)) is used to filter out and isolate AIDS virus and hepatitis type B in blood. Artificial blood vessels made from bio compatible polyester and Teflon fibres are commercially available to replace thick arteries or veins of 6 mm, 8 mm in diameter. A PBT smooth monofilament suture passes through skin without being caught and can be tightened with a single knot suitable for surgery. The poly glycolic acid suture is used currently for heart surgery in order to withstand the high pressure within the heart. Mitsubishi Rayon Co. has developed a micro porous PP hollow fibre for the manufacture of an artificial lung.

2.3 Overview of Nonwovens

Nonwovens are made using a set of inexpensive, high-speed principles for a range of applications with the goal of achieving the desired structure and qualities. Nonwoven technology allows for the bulk production at lower cost than the conventional woven and knitted technology. Nonwovens are made using the principles that are used in manufacture of textiles, papers, and plastics (Fig. 2.12). As a result, the structure and properties of nonwovens are quite similar to these materials. Fig. 2.13 illustrates end use applications of various nonwoven products in general and medical textiles in particular.

The following are the most prevalent nonwovens products, as identified by INDA:

- Agricultural coverings
- Automotive and upholstery
- Disposable nappies
- Filters
- Household and personal wipes
- Laundry aids (fabric dryer-sheets)
- Geotextiles
- Wall covering
- Carpeting and upholstery fabrics, padding and backing
- Apparel interlinings
- Blankets and felts
- Envalops
- House wraps
- Labels
- Tags
- Roofing products
- Sanitary napkins and tampons
- Sterile wraps, caps, gowns, masks used as medical textiles

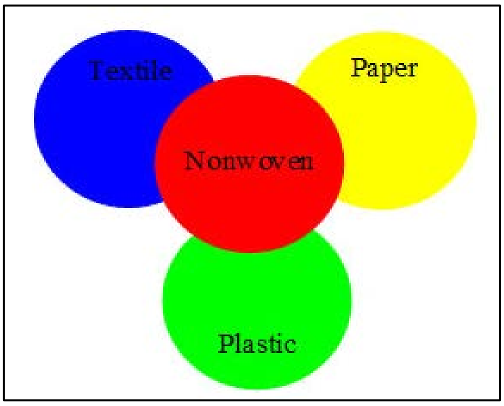


Fig. 2.12 Principle of Nonwoven Manufacture

2.3.1 Nonwovens in Medical and Healthcare

Nonwovens are widely employed in medical industry and for safeguarding against biological agents in various fields. They provide essential safety features, such as protection against infections and diseases. Nonwovens play a crucial role in combating cross-contamination and the transmission of infection in medical or surgical settings. In order to avoid contamination, disposable non-woven is more common as compared to woven fabrics. Due to their single-use nature and subsequent incineration, these items eliminate the requirement for handling and greatly reduce the potential for contaminant transmission. Significantly developed market of non-wovens is especially consumable textiles for operation theatre etc.

The advantages of using non-woven materials in medical and surgical textiles are shorter production cycles, lighter weight, flexibility and versatility and lower production costs. Nonwovens are used in disposable hygiene products such as diapers and sanitary napkins due to their softness, absorbency, and ability to facilitate moisture penetration. Nonwovens are utilised in the manufacture of adult incontinence and personal care products.

Fig. 2.13 End use applications of various nonwovens

Recent advancements in nonwovens technology involve the development of novel frameworks for 3D biological tissue engineering, fabric materials that can strengthen natural tissues when implanted, and filtration media made of nanofibers that have improved particle capture capabilities. Novel nonwoven materials with enhanced coatings, such as liquid-repellent, virus-resistant, and bacterial-barrier characteristics, have been created for use in surgical masks, gowns, and drapes.

Some of end-use applications of the nonwovens in medical and healthcare are listed as:

- Surgical: single-use caps, gowns,
- Drapes, wraps and packs
- Sponges, dressings and wipes
- Examination gowns
- Ostomy bag liners
- Fixation tapes
- Incubator mattress
- Sterilisation wraps
- Wound care
- Underpads
- Heat packs
- Lab coats
- Tissue scaffolding
- Isolation gowns
- Trans-dermal drug delivery
- Shrouds
- Contamination control gowns
- Procedure packs

2.3.2 Advantages of using Nonwovens in Medical Applications

Depending on the type of nonwoven for a particular application advantages can be listed as:

1. Protection against
   - dry or wet contact
   - air-borne particles
2. Custom-made for the operating theatre
   - procedure-specific design
   - optimum wearer comfort
   - strong yet light in weight
   - optimal fluid absorbency
3. Excellent barrier properties
   - exchange of air, body heat
   - good moisture retention
4. Excellent uniformity
5. Breathability
6. Abrasion resistance and lint free
7. Repellent
8. Self-adherent edges
9. Aseptic folding
10. Engineered stability for ETO, plasma, radiation, or steam sterilisation

2.3.3 Nonwovens in Absorbent Hygiene Products

Absorbent hygiene products (AHPs) have significantly enhanced the quality of life and skin well-being of people. These products offer distinct advantages such as softness, smoothness, leakage prevention, strength, and protection. Nonwovens find applications in infant diapers, feminine hygiene products, adult incontinence products, and personal care items. In these products the nonwovens used as certain components. For example top sheet or cover stock, leg cuff, acquisition/distribution layer, core wrap, back sheet, stretch ears, landing zone, dusting layer, and fastening mechanisms ensuring effectiveness and efficiency of health care products.

Absorbent surgical dressings are similar to wound pads used in surgery manufactured from well-bleached, carded and cleaned cotton nonwoven fabrics. Absorbent lint is cotton cloth of plain weave, warp nap raised on one side, by a process known as linting, used as external absorbent and protective dressing and for the applications of ointments and lotions, as antiseptic adsorbent and protective dressing in first aid treatment. Surgical and other gauze provide absorbent materials of sufficient tensile strength for surgical dressing made of cotton nonwovens. Thus nonwovens offer significant advantages in performance of absorbent hygiene products such as:

- Excellent absorption
- Comfort and fit
- Strength
- Good uniformity
- Stretchability
- Smoothness
- Softness
- Double fluid barrier/leg cuffs help prevent leakages
- Good strike through, wet back
- Cost effectiveness
- Stability and tear resistance
- Opacity and stain hiding power
- Breathability

2.4 Nonwoven Manufacture

The nonwoven manufacturing technology typically involves four fundamental processes: fibre preparation, web formation, web bonding, and finishing (Fig. 2.14).

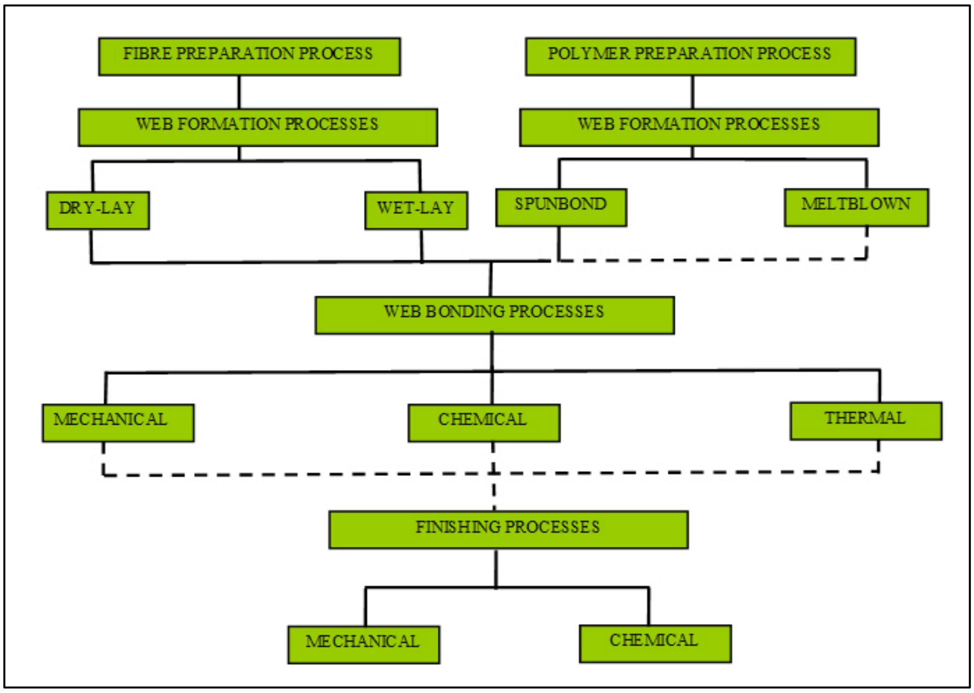


Fig. 2.14 Schematic diagram of nonwoven manufacture

(a) Dry-laid Process

The dry-laid process is arranging a network of fibres in a predetermined pattern usually by the aid of air or mechanical methods, in order to bind in to a fabric without the need for liquid binders (Fig. 2.15). This method is frequently employed to produce a diverse array of nonwoven textiles, such as filter media, insulating materials, and various technical textiles. The dry-laid process is a highly adaptable and effective method for manufacturing nonwoven combining fibres, such as polyester, polypropylene, or natural fibres like cotton, wool, or hemp, in order to produce a consistent amalgamation.

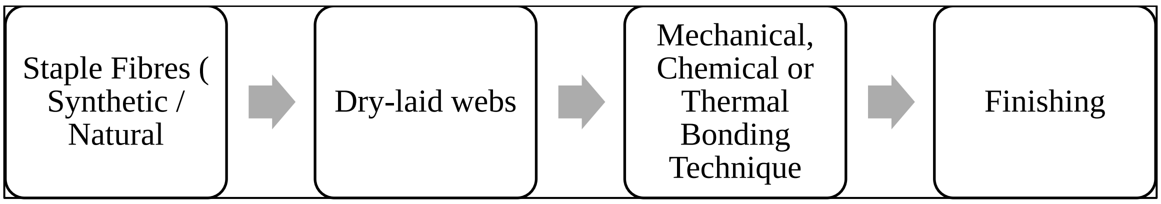


Fig. 2.15 Dry-laid bonded nonwoven process

Subsequently, the fibres are conveyed via a sequence of conveyors and devices that precisely arrange and disperse them in a predetermined configuration. In the dry-laid technique, the fibre web is bonded using mechanical or thermal bonding or needle punching. The fabric is with a consistent density, robustness, and thickness that can be customised to fulfil precise performance criteria.

The dry-laid process offers a significant benefit in its capacity to produce nonwovens that possess characteristics, such as filtration, insulation, sound absorption, and durability. These textiles have versatile applications in various sectors, including automotive, construction, consumer goods, and medical.

(b) Wet-laid Process:

Hydro entanglement is a mechanical bonding technique to convert short staple synthetic fibres in to nonwovens that have a similar texture as woven and knitted fabrics. Water jets cause the insertion of surface fibres into the fibrous web, displacing and rotating them around surrounding fibres. A conventional hydro entanglement procedure involves directing one or more rows of tightly spaced water jets, under high pressure, onto the fibre web that is held in place by forming wires (Fig. 2.16).

This leads to the twisting and entanglement of fibres with neighbouring fibres. The cloth is bound by the inter-fibre friction. The fibres undergo carding in the carding machine and are then entangled in the hydro-entangling unit. Following hydro-entanglement, the moisture in the fibres is extracted by the drying procedure. If required, a finishing procedure can be applied to the fabrics, after which they are rolled onto rolls for subsequent processing.

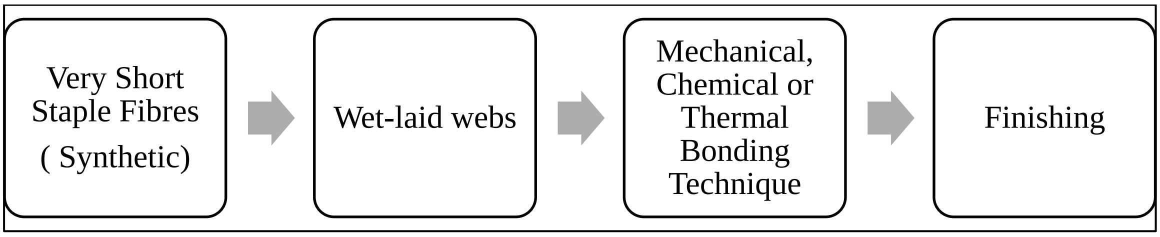


Fig. 2.16 Wet-laid bonded nonwoven process

(c) Spun-bonding Process:

Spun-bonding is a continuous manufacturing process either from chemical or polymer stage to the finished nonwoven products i.e. web formation, web bonding, and winding into rolls. Polymer melt is fed into an extruder and forced through a spinneret; the fibres are then stretched, quenched to form the web continuously onto a moving conveyor belt. The loose fibres web may be bonded by one or more of the three bonding techniques: mechanical bonding, thermal bonding, chemical bonding etc. (Fig. 2.17). This process is used only for thermoplastic polymers such as polyester, nylon, polypropylene, or polyethylene.

(d) Melt Blown Process:

The melt blown method is distinct among nonwoven systems. Essentially, it is an advanced technological rendition of the process of creating cotton candy commonly seen at amusement parks. Cotton candy is produced by melting sugar and then forcing it through narrow apertures in a rotating wheel. When heated, the liquid sugar solidifies and is elongated into brief strands due to centrifugal forces. In the melt blown system, liquefied polymers are pushed through narrow slits while hot air, ranging from 230°C to 390°C, is directed at high speeds of 300-500 miles per hour on both sides of the resulting film.

The high-velocity air currents efficiently elongate to form into a haphazard arrangement of fragmented fine fibres. The fibres are subsequently compacted (isolated from the airflow) into interwoven mesh and crushed between heated cylinders. The final product is very thin, delicate having few micron pore size having potential for diverse applications especially in filtration of micro particles. The combination of Spun bond-Melt blown-Spun bond process produces SMS nonwoven having sandwich structure very effective in face mask, important health care application preventing virus during inhaling.

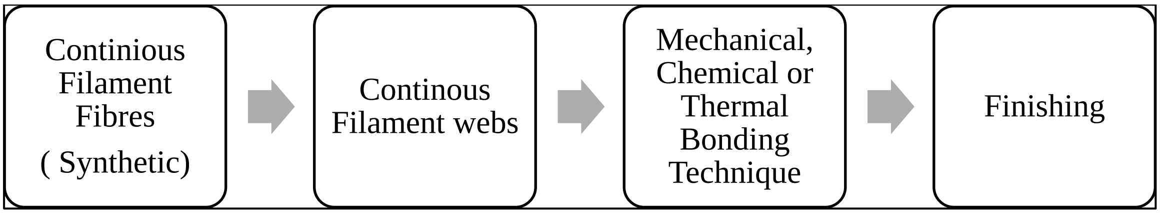


Fig. 2.17 Spun-bonded nonwoven process

2.5 Disposable Hygiene Products

Most hygiene products are disposable. Typically, these products include tampons, diapers, sanitary napkins, panty protectors, and wipes. These materials and structures must be: (i) highly absorbent, both for the purpose of containing liquid and solid waste; (ii) gentle on the skin of consumers; and (iii) cost-effective. Manufacturers produce the majority of them using extremely thin and low-cost nonwovens. The sanitary napkin is a common disposable absorbent product. The pattern of development of products for sanitary napkins is, for the most part, comparable to the pattern of development for diapers. To make the product more comfortable (that is, smaller and softer) and/or efficient (that is, more absorbent and/or less likely to leak) is the overarching objective of the design and development process. Along the same lines as the diaper, sanitary napkins are the disposable hygiene textiles has a structure that is composed of multiple layers. Its construction often includes three layers: the top sheet, the absorbent layer, and the back sheet.

2.5.1 Diapers

Incontinence is a problem that commonly occurs in the elderly and adults with particular illnesses. People who have difficulty in managing continence may need the support of incontinence products to contain urine leakage to maintain personal hygiene care to have a better quality of life and carry out their daily lives confidently. Diapers are the most common absorbent products that can provide healthcare hygiene support to those with an incontinence problem. Adult diapers are either disposable or reusable, and they are generally applied for moderate or heavy incontinence management.

2.5.2 Sanitary Napkin

Sanitary napkin or pad is generally made up of set of layers of various materials that fulfils the absorption and comfort properties. These layers are typically known as Top sheet, Acquisition Distribution Layer (ADL), Absorbent layer and Back sheet, all are generally made up of various textiles and functional structures. The main materials of disposable menstrual pads are usually bleached rayon (cellulose made from wood pulp), cotton and plastics. In addition, fragrance and antibacterial agents can be included. The plastic parts are the back sheet and polymer powder as an additional powerful absorbent (superabsorbent polymers) that turns into a gel when moistened (Fig. 2.18) [43].

The top sheet is generally remains in contact with body skin and receives body fluid during the use of the product. It is made up of polyethylene film or polypropylene nonwoven fabric. Next to the top sheet is acquisition distribution layer that spreads fluid beneath the absorbent layer. This layer is made up materials such as wood pulp and superabsorbent polymer (SAP) using air-laid nonwoven technology. The back sheet, a bottom layer is an impermeable film. The ADL and absorbent layers are woven fabrics however the absorption capacity of nonwoven fabrics is better and quicker hence provides more comfort to the user. The feel of dryness and leakage elimination are not remarkable. Likewise, the gelation property of the absorbent layer and administration of moisturisation have to be performed on the top sheet and acquisition distribution layer.

- **Superabsorbent Material in Disposable Healthcare Products:** Superabsorbent materials (SAMs), which are made from superabsorbent polymers (SAPs), have the property of absorbing and retaining huge amount of aqueous solutions. The absorbent hygiene products can be made thinner because smaller amount of SAPs ca A SAP's ability to absorb water depends on the ionic concentration of the aqueous solution. In deionized and distilled water, a SAP may absorb 300 times its weight (from 30 to 60 times its own volume) and can become up to 99.9% liquid, and when put into a 0.9% saline solution the absorbency drops to approximately 50 times its weight and absorb the same volume of aqueous liquid as larger amount of fluff. For this reason, they are widely adopted in the manufacturing of disposable healthcare products such as diapers, feminine care products and adult incontinence products. SAPs are originally either natural or synthetic materials.

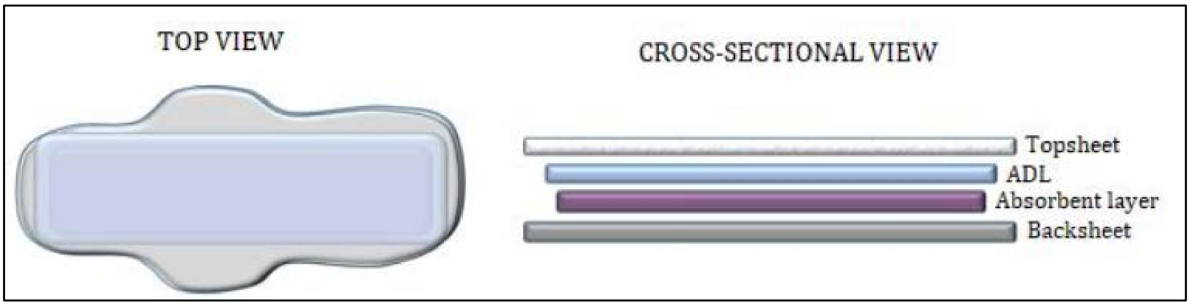


Fig. 2.18 Construction design of typical Sanitary napkin

2.6 Strategies for Hygiene Products

Hygiene products should either disposable or reusable but should be economical, more protective and less environmentally damaging [44]. Single-use disposables can be convenient and cheap, but they can also contaminate the environment and be expensive. Walton, a Disney expert, advised on type selection. Since buying cleaning and decontamination instruments would be expensive, disposables should only be used in low-volume settings [45]. Buyers should include reusable hygiene products with safety clothes and other PPE.

Third-party reprocessing companies save 30–50% by relieving the healthcare unit of the cost of cleaning and disinfecting frequently used objects without having to buy their own equipment. Original equipment makers don't always like these arrangements. They may add "kill switches" to original devices to prevent reprocessing or buy out reprocessing companies to make more money instead of coming up with new ideas to help healthcare providers and patients [46].

An Australian group studied the environmental impact of healthcare [47]. They wanted to help people who work in the healthcare sector to take steps to reduce the negative effects on the environment. They looked at seven environmental stressors with known negative feedback cycles such as:

- Greenhouse gas emissions
- Particulate matter
- Nitrogen oxide air pollutants
- Sulphur dioxide as an air pollutant
- Malaria risk
- Reactive nitrogen in water
- Scarce water use

Based on the study, a group in New Zealand said that healthcare, if it were a country, would be the fifth biggest polluter in the world because it produces almost 5% of all carbon emissions. They also gave six suggestions for reducing the sector's negative effects on the environment and, often, its wasteful spending:

- Reduce the number of flights taken and offset the carbon emissions on all flights
- Choose clean energy

- Opt for reusable items
- Incentivise staff to consider alternative transport options
- Reduce meat and dairy options
- Choose medical devices which can be remanufactured

Items that can be reused and medical items that can be remanufactured are included on that list [48]. Regulation (EU) 2017/745 of April 5, 2017 on medical devices (EU 2017) says that remanufactured "single-use" medical devices must meet manufacturer standards and get a CE mark to show that they are just as safe and effective as new equipment. They also have to be sterilised to the same level as the original device. Healthcare units that want to save money and handle the growing need to make less waste but are worried about how much it will cost to clean and disinfect can now find systems and goods that will help them reach their goals.

2.7 Feminine Hygiene Products

There are a lot of options for feminine hygiene products right now. The market was worth US$20.9 billion in 2020 and is expected to reach US$27.7 billion by 2025, growing at a rate of 5.8% per year (Markets and Markets 2021). While negatively impacting women and girls worldwide, a business known as "period poverty" generates significant profits. The term refers to the situation in which individuals are unable to obtain sanitary items due to financial constraints. Action Aid 2021 estimates that one in ten girls in Africa do not attend school due to a lack of access to sanitary goods and that twelve percent of menstruating women in India cannot afford period products. In 2017, reports indicated that one in ten girls in the UK were unable to purchase sanitary products and resorted to using makeshift sanitary wear instead [49]. Murugananatham has innovated grassroots mechanisms to generate awareness about traditional unhygienic practices surrounding menstruation in rural India [50]. He is also the inventor of the low-cost sanitary pad-making machine. However, poverty is not limited to poor countries.

The government removed the 5% value-added tax on sanitary goods, also known as the "Tampon Tax," in 2020. This was a positive step in the right direction (GOV.UK 2021). Consumers are likely to shift towards biodegradable and safe options, or options that can be used multiple times. Because of worries about the environment, people are moving towards non-applicator tampons (which cut down on the waste from the applicator), silicon menstrual cups, and washable, reusable clothes like period panties. The most important thing is to make the product at reasonable price so that poor people in both developed and developing countries can afford them.

Since cellulose fibre was found to be more effective at absorbing blood during World War I than woven cloth bandages, Kotex created the first cellulose sanitary napkin in 1918 using extra-high-absorption war bandages [51]. By 1921, it had become the first sanitary napkin to be successfully mass-marketed.

Due to hygienic concerns over the closeness of pads to faecal microorganisms, modern disposable tampons were developed in 1933 and were frequently considered a healthier option than pads [52]. Tampons were already being used in medicine to halt serious wound bleeding. Tampons would be unsuitable, so Dr. Mary Barton addressed issues in a British Medical Journal publication. She emphasised that, in contrast to sanitary pads, tampons did not produce vulva boils and abrasions [53]. Mary Beatrice Davidson Kenner created the sanitary belt in 1956 as an alternative to pads by including glue to keep the pad in place. Ongoing research led to the creation of the first beltless pads in 1972. In 1980, the company launched a range of pad styles and tampon absorbencies.

In 1978, toxic shock syndrome (TSS) entered the medical lexicon. It became well known in the public eye in 1980 after an outbreak in the USA. Researchers confirmed the link between TSS and tampons, particularly Proctor & Gamble's brand called Rely. The carboxymethyl cellulose and nylon beads were pressed together to make this tampon. Studies have shown that other brands, mainly made from cotton and viscose rayon, are less absorbent than this one [54].

It wasn't until 1976 that tampons had to pass medical testing rules in the United States. After the TSS outbreak, the US Federal Drug and Alcohol Administration started requiring guidelines for absorbency. In 1989, researchers linked TSS to man-made products such as carboxymethyl cellulose, polyester, polyacrylate rayon, viscose rayon, and others. The man-made materials made it easy for the harmful bacteria Staphylococcus aureus to grow. As a result, researchers phased out these products [55].

Researchers explored natural polymer options such as cotton, rayon, or a combination of the two due to the TSS outbreak (Tampax® 2020). Researchers tested many alternatives, including reusable menstruation cups, period sponges, and biodegradable choices, in response to the growing feminist movement and increasing focus on environmentalism. As the understanding of menstruation and anatomy has advanced, the designs of the tampon have been modified. During the 1990s, prominent tampon manufacturers transitioned from utilising chlorine gas bleaching procedures that produce dioxin to employing chlorine-free bleaching processes. Although there is ongoing debate on the presence of dioxin at even minimal concentrations, FDA currently advises manufacturers to disclose any potential chemical residue on their product labels (FDA 2020a).

2.8 Sanitary Napkin Usages and Selection Criteria

Menstruation, often known as the menstrual cycle, is an integral aspect of the female reproductive system that commences during the onset of sexual maturity in females during puberty. In the absence of conception, woman will experience menstruation at an approximate interval of 28 days. During the physiological process of menstruation, a female individual experiences the discharge of blood from the uterine cavity, which subsequently exits the body through the vaginal canal. The duration of this event typically called menstrual phase of averaging 5 days but can ranges from three to seven days (Fig. 2.19).

The blood expelled during the typical menstrual cycle is normally below 80 millilitres. Most women use sanitary napkin during these situations even though other options are available. Women tend to change their napkins every 2-4 hours. It is observed that the changing cycles tend to be lowered after three days due to reduction in the fluid discharge.

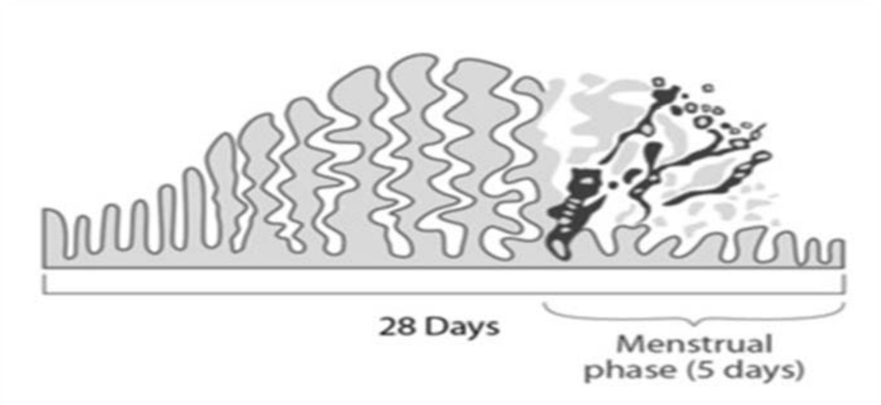


Fig. 2.19 Menstruation cycle

2.8.1 End-user Preferences

The consumer preferences information assists in gaining insight of producer. The television is the primary source of promotion, followed by other women's recommendations. Sukram Kara [56] studied about the expectations from sanitary napkins and its functional design. She surveyed 500 Turkish women and found that women prefer to pay extra for a more protective sanitary napkin. They think sanitary pads contain harmful substances that can damage their skin. Thus, they choose natural sanitary pads. The study discovered a connection between period frequency and alterations in sanitary napkins. The survey of respondents was based on background details of sanitary napkins, such as “expectancy from napkins,” “functional properties to be added in sanitary napkins,” “sanitary napkin usage habits” and “Sanitary napkin preferences.” The demographic information of respondents includes age, accommodation, and occupation data having a wide variety of jobs.

2.8.2 Sanitary Napkin-Expectancy:

The study shows that the performance characteristics are one of the vital questions wherein absorption and leakage prevention are significant. Women focused on odourless and soft surfaced napkins in addition to the absorption properties such as leak-proofing and dryness. The most minor significance is given to other characteristics such as breathability, mobility, wings, thickness, and usability as shown in Fig. 2.20. .

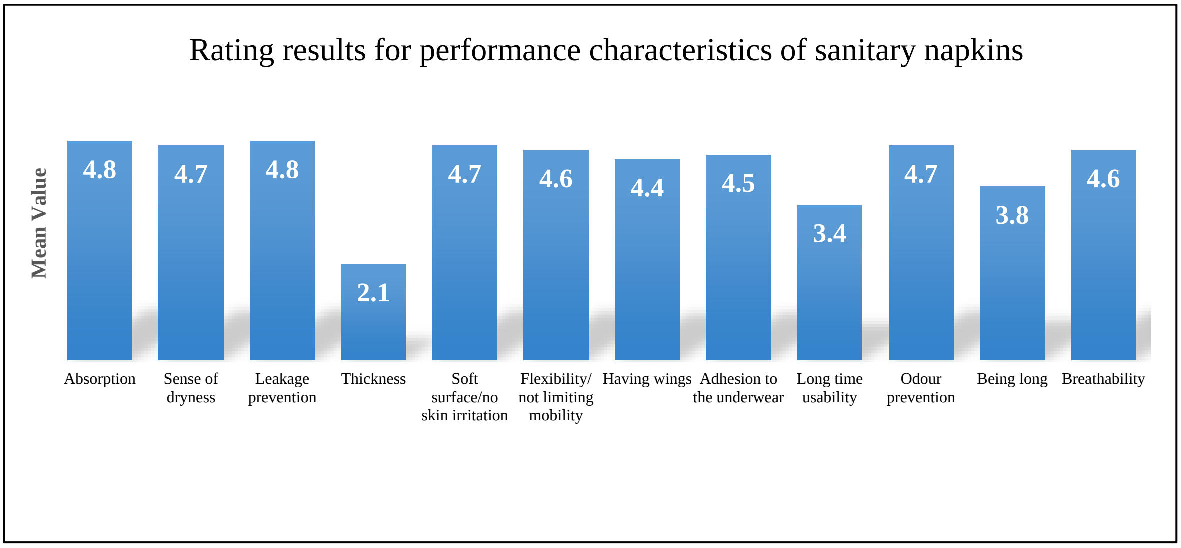


Fig. 2.20 Expectancy from sanitary napkins using Likert scale analysis

Sanitary Napkin - Selection Criteria

Relied on the performance properties, the buying behaviour of the sanitary napkin could be analyzed. The most minor significance is given to having perfumed. Women look for odor prevention rather than perfumed ones. Compared to price, brand, and biodegradability, the sanitary napkin made from natural raw materials gained the highest significance as shown in Fig. 2.21. In addition, few problems like rashes and infections are least experienced by women.

The survey has also stated the functional characteristics of designing sanitary napkins. Most women expect to have antibacterial properties and few demand painkiller properties. The top sheet is coated with topical painkillers, which could relieve vulva-related pains. However, other properties like reusability, soothing and moisturizing properties, and drug delivery are not expected. There were statistically significant differences between the ratings depending on the age groups. According to the women's age, the functional properties differ in using sanitary napkins such as leakage prevention and having wings. Functional properties required in sanitary napkins such as wetness, allergy, etc., are found to be important but women did not prefer perfume on sanitary napkins to hide odour but they wanted an antibacterial system.

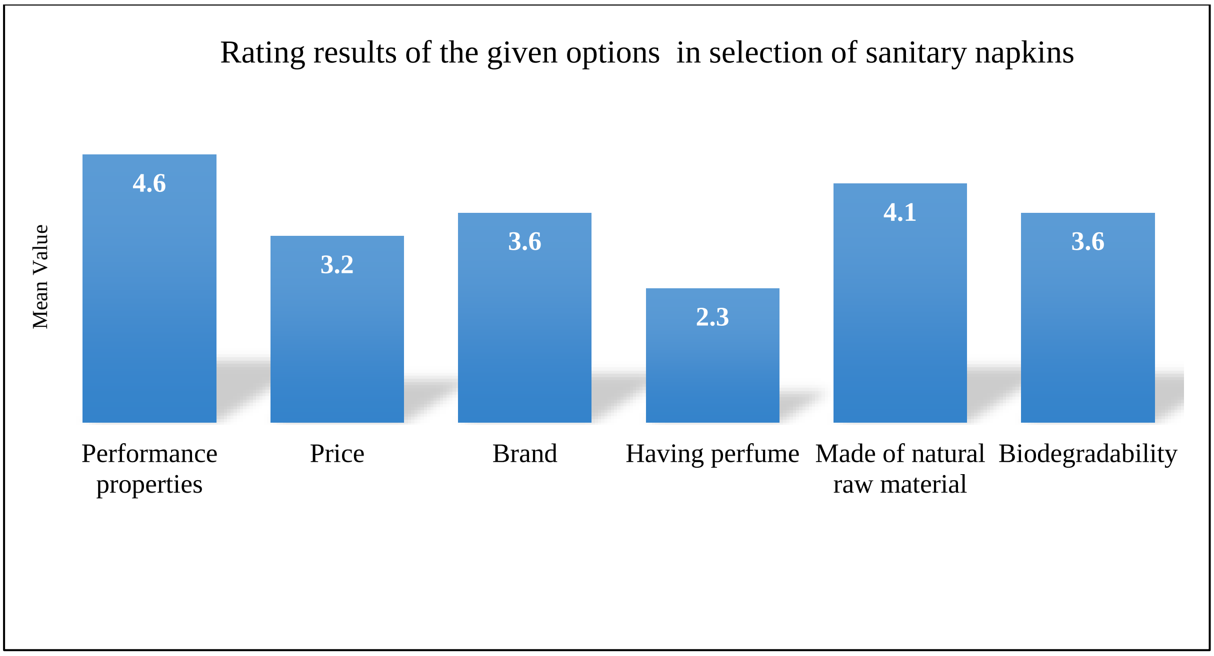


Fig. 2.21 Selection process of sanitary napkins using Likert scale analysis

2.9 Medical Textiles related Standards

(a) Bureau of Indian Standard (BIS):

BIS is an Indian Standard body responsible for establishing standards, conducting tests, affixing quality marks, and certifying the quality of products. BIS manages a variety of certification schemes designed to guarantee that customers receive products of high quality and devoid of risks.

(b) European Standard EN 13795:

The standard defines interruption properties in surgical uniforms. It ensures the production design for all safety parameters. It also mentions the performance, modelling, requirements processing, and testing methods for all levels of medical personnel [57]. Different testing methods ensure the manufacturer process's resiliency and tensile and bursting strength. It has four test methods classes: Class I, Class II a, Class II b, and Class III.

(c) Occupational Safety and health administration (OSHA):

This standard ensures the risk reduction in blood-borne infections such as AIDS, HIV and some invasive procedures. To prevent infections, OSHA 1991 set standard to ensure the quality of Personal Protective Equipment (PPE) including gowns, masks, face shields, and gloves. The proper use of PPE is adjourned by eliminating the contaminated fluids. Likewise, the PPE selection relies on the exposure level to the body fluids during the tasks. The sorts of PPE are the [58]:

- Exposure constraints include pressure, fluids, droplets, and aerosols on the face, legs, and hands.
- The quantity of blood.
- The duration of exposure

OSHA has also presented that the uniform should not be taken home and that the cleaning process must be followed consecutively.

(d) Centres for Disease Control and Prevention (CDC)

The role of the CDC is to ensure the prevention strategies for Surgical Site Infections (SSIs). It applies to all medical staff and patients infected or suspected. This standard covers the association between healthcare providers and end-users based on the exposure level of pathogens, body fluid, and blood [59].

(e) Association of Peri Operative Registered Nurses (AORN):

It ensures the protection and quality of care for registered nurses. The practices are recommended using education, services, and representatives. The passage of bacteria must be eliminated. It acts as a better barrier between sterile and non-sterile areas. It must address other needs like tear tolerance, punctures, abrasions, and flexibility.

(f) Association for the Advancement of Medical Instrumentation (AAMI):

This standard provides a reliable benchmark for the clinic scenario. It looks for better fabric administration during medical procedures. It has four tests: Spray Impact Penetration Test, Hydrostatic Head Test, ASTM F1670, and ASTM F1671. Each has barrier testing to mitigate the effects of blood penetration and other body fluids [60].

(g) American Society for Testing and Materials (ASTM):

ASTM portrays the test methods of the products for the manufacturers. The standards are applied to the design of products and its limit.

(h) American Association of Textile Chemists and Colorists (AATCC):

AATCC includes the test methods of fabrics to measure the appearance, release of dirt, dimensional change, and the water-tolerance.

2.10 Comparative Test Analysis – Available Sanitary Napkins

Women have improved how to cope up with menstruation using natural and artificial materials. Among the various famine hygiene products mostly sanitary pads are in used by majority of women. There is wide range of these products available in the market. The comparative analysis of the different brands is given Table 2.3 to gain insight into sanitary napkins. The brands are lab-tested based on their performance properties, which are discussed. It is inferred from that, Caremate is the best to purchase and also the best value for the money. From the test analysis, Caremate ranks top, followed by Carefree and Kotex. It is ranked from the aspect of the absorbency test. Brands like Don't Worry, Sofy, She, and Whisper passed the disposability tests by following Indian standards. It forms a lump in the water during disposal. Whisper has the best sensory test reports, followed by Caremate and She.

Table 2.3 List of brands and its details

Sr. No.	Brand name	Feature	Type	Size (length) (mm)	Cost (Rs)	Count of pack
1	Caremate	Active choice medium flow	NA	240	45	20
2	Kotex	Soft and smooth	Regular	230	50	20
3	Carefree	NA	Regular	465	105	20
4	She	Select comfort	NA	230	20	8
4	Stayfree	Secure cottony soft	Regular	230	52	20
5	Whisper Choice	Choice wings	NA	240	26	8
6	Don't worry	NA	Ultra-thin regular	240	32	6
7	Sofy	Side wall dry slim	Large	260	99	15
8	She	Ultra comfort	Extra large	284	99	30

***NA (Not applicable)**

The ideology of the sanitary napkin is to captivate and hold the blood discharges. It has an adhesive strip placed beneath the undergarments. It is essential to stay in place and be comfortable to wear. The shape, absorbency and lengths may vary depending on manufacturer, but usually range from the short slender panty liner to the larger and longer overnight. Long pads are offered for extra protection or for larger women whose undergarments might not be completely protected by regular length pads.

The proliferation of length, width, and thickness determines the size of the pad. As per the Indian Standards, depending on the size, length ranges from 180mm to 220mm (regular), 220 to 260mm (large), and 260mm to 300mm (extra-large). This has sufficient coverage. The width of the napkins ranges from 60mm to 75mm. The thickness relies on the surface area of the napkin and its categories, like regular, large, and extra-large. The thickness metric also depends on the suitability of the women. The general details of the napkin size are given in Table 2.4.

Table 2.4 Dimensional Specifications of sanitary napkins

Napkin type	Length of a pad (mm)	Width of a pad (mm)	Thickness of a pad (mm)
Regular	200 ± 20	60 to 75	15 ± 2
Large	240 ± 20		
Extra large	280 ± 20		

The various features and parameters of the sanitary napkins of different types available in the market summarized as follows:

- **Absorbent filler:** The absorbent layer contains cellulose pulp, wadding, and cotton tissue. It assists in removing lumps, sports, or any foreign materials.
- **Absorbency and absorbability:** The napkin should be able to absorb the fluids without showing any stains or leakage at the sides and bottom.
- **Wet back Covering:** According to the Indian Standards, the filler should be of better quality, made up of cotton or rayon, gauze, or any nonwoven fabric.
- **Adhesion/stay in place:** The ability of the pad to stay in place and adhere to the garment properly during the usage.
- **Disposability:** The absorbed material in the sanitary napkin must be removed in 15L of water. It should not take more than 5 minutes.
- **pH:** The sanitary napkin should be unrestricted from acidic and alkaline materials. The pH value should be in range from 6 to 8.5.
- **Finishing Quality and Workmanship:** The absorbent filler should be appropriately designed according to the volume of the pad, and a suitable thickness should be maintained without any deformity. The proper covering deals without lump formation under specific pressures.
- **Packaging:** Polyethylene-lined carton or polyethylene bag is used for packaging purpose. Relied on the satisfaction of performance properties, the packaging is done.
- **Marking:** Each carton holds the manufacturers' details, the sanitary napkins count, the retail price, and the instruction for use and disposal.

2.11 Motivation of Present Study

Menstrual hygiene is the most ignored issue in these modern days due to its most minor focus. It becomes a barrier to women's health that keeps away their participation in the social activities which affects the quality of lifestyle. Even though there is much inclination in this field, there is not a generalized solution to the used material types that would be optimal for this application. Most developments search for a better supply chain system (or) the manufacturing process - some Western solutions, such as menstrual cups. Tampons are not produced locally. Most studies look for inexpensive and valuable materials to optimize the composition of sanitary napkins. Reusable is the possible solution to eliminate waste and create a sustainable environment. Several modern technologies have been introduced to propagate menstrual pads to meet all the requirements. The deployment of invasive absorbents is also culturally prohibited. Henceforth, local production with an economically feasible solution is the best.

The development made in sanitary napkins has very old history that takes roots back to 19th century. In the 1920s, American women designed handmade napkins using cotton, rags, etc. [61].The early patents have shown different designs of the napkin. Super Absorbent Polymers (SAPs) have been now introduced in the design having cross-linked and lightweight polymers. Non-woven pads, absorbs the fluid faster, but its thickness needs to be minimized where as superabsorbent materials failed, but resilient materials are scratchy [62, 63].

Many materials have been combined together to enhance the absorption property. For instance, sodium carboxymethyl cellulose is combined to enhance the area of the napkin surface using transverse Webber [64]. In another design higher absorbency is achieved by introducing a set of layers, namely, the barrier, reservour, transfer, and cover layers [65]. Here, the barrier and reservour layers are of high-density, whereas the cover layer is of low-density. Few designs have an absorbent layer made up of cellulose filled with attapulgite, which means aluminum silicate at the surface. The surface area increases using porous agglomerates and a nonwoven polypropylene separation layer. This material absorbs fluid 30 times better than other napkins [66].

Despite all this, advanced technologies like super-absorbent hydrogels are restricted in the marketplace. Henceforth, substantial work must be done to enhance menstrual hygiene choices for women in this developmental world. On the flip side, some of the Western solutions are also inaccessible. The properties of the designed napkin must be optimal and tested for all sorts of novel solutions. Studies focus on unusual materials like cotton and banana fibres to explore the high quality of the material [67]. Various technologies and new products are introduced to fulfil menstrual hygiene needs. The local production of recyclable pads is increased to enhance economical sanitation products.

The characterization of the fabrics has been made using textile standards regarding the performance of materials, tolerance, thermal resistance, etc. The motivating factors that lead to the better design of sanitary napkins are the absorption and comfort properties [68].

2.11.1 Absorption

Absorption is the characterization of absorbing the fluid's uptake and also explores the holding capacity of the material. The absorption potentialities are measured from the size of the particles, relative composition, and orientation. The various studies estimated aggregate mean menstrual flow to about 51g [69]. Several studies have been conducted to develop the absorption ability of fabrics using different means. The water absorption value of the material is studied to determine the efficacy of superabsorbent fibres [70]. In a personal interview in 2014, Steven Warner, Professor at the University of Massachusetts, Dartmouth, portrayed the rapidity of vertical wicking for the uptake of menstrual flow and the contact angle for measuring the wetting.

2.11.2 Comfort

Comfort is characterization of the fabric performance under a set of certain characteristics such as "feel" the fabric which includes its fullness, stiffness as well as fairness. The comfort properties of the yarns and the woven fabrics are studied by (X, Y). Similarly to it, the surface characteristics of the fabrics have been evaluated to quantify air and water permeability [29, 71]. Other measurements, such as heat transmittance, hydrophilicity, and water absorbance, have also been studied [72-73].

The above two measurements, comfort, and absorption, are the most important in designing a sanitary napkin. It should satisfy both properties; thus, no single design is considered an effective solution. The differences in materials narrow downs the choices for developing an optimal design. The collected information is passed through user testing to design locally, even across borders.

2.12 Evolution of Menstruation Products

During ancient times in Greece, women commonly used homemade cloth to regulate menstrual blood flow as shown in Fig. 2.22. It is worth noting that specific assertions suggest that women in ancient Greece employed lightweight wood to fashion rudimentary forms resembling tampons.

Women ingeniously fashioned their sanitary pads or cloths from woven cotton in ancient Rome due to its exceptional absorbency. In addition, women devised improvised sanitary pads using sheep's wool. Although it is less porous than cotton, it effectively fulfilled its intended purpose. Nevertheless, it is worth noting that woollen pads frequently retained a potent scent of blood and exhibited more thickness and weight than cotton pads (Fig. 2.23).

It is widely acknowledged that the ancient Egyptians are commonly attributed as one of the earliest civilizations to employ papyrus, a material derived from an aquatic plant's stem, for producing paper sheets, baskets, mats, sandals, and rope. According to historical records,

Fig. 2.22 Homemade Cloth – Greece

Fig. 2.23 Homebased pads from woven cotton – Roman

it has been postulated that women in ancient Egypt fashioned a device like a tampon as shown in Fig. 2.24 by shaping softened papyrus, which was then utilized to absorb menstrual blood. In ancient Africa, Grass was used in some form a pad or a tampon by women to absorb menstrual blood. It was kind of like a patch made of grass and vegetable fibre. The first shape was a pad. Fabrics used to make from vegetable fibre, flax or cotton. Rolls of grass and roots were used to make the tampons as shown in Fig. 2.25. Menstruating was an offensive matter amid men and women. Women were stimulated to have it to themselves. Home-based pads were prepared from normal requirements such as Cotton fibre and waste, Oil silk which was more accessible to wash as illustrated in Fig. 2.26.

Fig. 2.24 Tampon-shaped device – Egyptians

Fig. 2.25 Design of grass mats – Africa

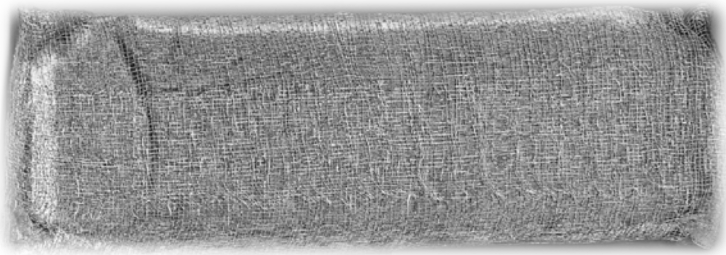


Fig. 2.26 Homemade pads - 17th Century (Europe)

2.13 History of Sanitary Napkins

Earlier in 1896, homemade sanitary napkins were used globally. Commercial sanitary pads were introduced by Johnson & Johnson. These napkins were designed to absorb the fluid, which varies in different parts of the world. Soft papyrus, wood covered with lint, moss, cloths, rags, grass, and animal skins were used to design the sanitary napkin. Nurses use cellulose bandages, which had better absorbency properties during World War 1. At the same time, American ladies use napkins attached to muslin belts to escape from clothes staining. In 1920s, Kimberly-Clark introduced Kotex napkins on the store walls, wherein women did not feel shy about purchasing them. The use of belted napkins was further improved by closed crotched underwear. Tube tampons and menstrual cups were also introduced in the 1930s. The design of adhesive stripes in 'Stayfree' put an end in the 1970s.
In the Ancient world, softened papyrus was used as a tampon. In Greece, lint wrapped in wood pieces was used as tampons, and in Rome, pads and tampons were made up of soft wool.

The chronology of developments of sanitary related products is listed below.

- 1839, Charles Goodyear introduced vulcanized rubber technology. It manufactures condoms, syringes, and intrauterine devices.
- 1850s many products, such as cat menial sacks and bandages, were introduced from the springs, wire, buttons, valves, and girdles.
- 1873, the Comstock Act was passed to distribute or sell conception-oriented products in the US.
- 1896, the first commercial sanitary pads were introduced by Johnson & Johnson, which reverted the proverbial rock.
- 1920, disposable pads that have a combination of cotton and texture had been introduced by some co. such as Kotex, Stayfree, and Freedom. However, it was needing a belt to fix it to stay in place.
- 1927, Modess was introduced by Johnson & Johnson, varities of napkins were manufactured.
- 1969, first sanitary napkins with adhesive strips were launched by Stayfree.
- 1985 Courtney Cox Arquette was introduced in a TV commercial ad.

At last, the FDA approved the birth control pill and suppressed the periods in 2003 and 2007. A variety of sanitary napkins are being utilized by women all over the world. As shown in

Fig.2.27 cloth or reusable napkins are an environmentally friendly option; nevertheless, it needs proper washing with disinfectant in a sanitary manner and then dried in direct sunlight which is natural disinfectant. However, drying in the open sun was prohibited in India due to several superstitious beliefs that are prevalent.

Currently wide verities of Napkins for sanitary purposes that are sold commercially are readily available in the shopping centre (Fig. 2.28). These are normally constructed using different forms of polypropylene and polyethylene, both non-biodegradables. It is believed that the cotton or wood pulp utilized as the stuffing contained pesticides and would not be considered natural. If the superabsorbent polymer used in commercial napkins is flushed down the toilet, it could cause a clog in the plumbing system.

Commercially available sanitary napkins contain:

- Cellulose wood pulp
- Superabsorbent polymer (SAP)
- Polypropylene nonwoven core
- Polyethylene back sheet

Fig. 2.27 Cloth / reusable sanitary napkins

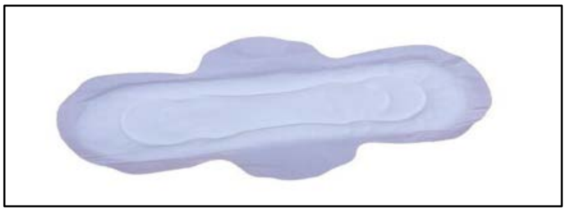


Fig. 2.28 Disposable Sanitary napkin

2.14 Environmental Impact of Menstrual Products

Many women around the world can't choose which sanitation products to use. In some cases the culture affects how they use menstrual products as peoples traditionally believes that it is inappropriate to use internal menstrual hygiene products like sanitary napkins [74, 75, 76]. When a person has the option to choose menstrual goods, number of factors affects their choice [77]. The disposable menstrual pad is the most popular menstrual product used around the world [75]

Jyoti Choudhary and, Dr Mahua Bhattacharjee [75] studied the consumption pattern of sanitary napkin and environment degradation analysing the secondary data linking the sale data of two leading firms manufacturing these products. They concluded that more than 60% of women are aware that synthetic sanitary napkins cause environment pollution; where as only 30% of women know about eco-friendly pads. In addition, 99% of women wrap sanitary napkins up and throw them in the trash in an unsanitary manner. These prefer cheaper synthetic sanitary pads that harm the environment.

The measurement of the influence of menstrual products on the environment is a difficult task, and there is a severe dearth of scientific literature that investigates how these concerns are affected. The quantity of menstrual waste produced, the amount of fossil fuels depleted, the amount of minerals used, and the amount of petrol emissions in product-manufacturing processes are some of the factors of environmental impact [75]. In other words, menstrual products have an adverse effect on the environment because of raw materials, energy, and water consumed [75, 76].

Women's disposable sanitary goods like pads can have up to 50% plastic as an ingredient, and most of these pads end up in landfills [77]. Most disposable pads are made of cotton mixed with rayon or other synthetic fibres like polyethylene and polypropylene. The pads usually contain even more polymeric materials than that of tampons do, like bases that won't leak and/or extra-absorbent strips [78]. Pads are either discarded as inert trash once they have been used or thrown away as regular trash; they either end up in dumps or are burnt in incinerators [79]. Although disposable pads are supposed to degrade in about 500 to 800 years in a dump, some materials, like plastic, never really do so [73, 75]. This is of important concerns as each person on average uses 5,000 to 15,000 pads and tampons during the life time [77].

According to research that compares the environmental effects of different sanitary products, the disposable menstrual pad seems to have the biggest effect. This is because it uses the most minerals and fossil fuels to make, has the biggest carbon footprint, and makes the most wet and dry waste [75]. Different municipal waste management techniques and disagreements over how to classify menstrual waste make it unclear how to discard and dispose of used items, which may lead to improper disposal [79]. In addition to these disposable waste products, the packaging of these products also generates about 400 pounds of trash annually par woman [78].

The used products also affect ocean lives and the sea water. It disintegrates in to microscopic plastic pieces when disposed off and their plastic packaging material also break down in to smaller pieces. Scientists concluded that these micro plastics pollute the marine environment which is a major threat to ocean biomes [79]. Also, menstrual products that are flushed down the toilet have a direct effect on marine environments. Single-use menstrual products and their packaging materials are commonly found on beaches and in sea water [80, 81, 82, 83].

Satoko Ishii *et*. al. [84] conducted a risk assessment study to assess the potential hazard of dioxins in sanitary pads used in Japan. The seven fluff pulp samples analysed in this study emitted dioxin at levels ranging from 0.000024 to 0.00042 picograms of toxic equivalency per kilogramme per day. There was a notable disparity in the levels of dioxins found in sanitary napkins ranging from 1666 to 29166 times less than the TDI (tolerable daily intake). The majority of the dioxins identified in this investigation were not the typical dioxins produced during the bleaching process of fluff pulp. These findings indicate that the daily intake of dioxins from napkins is significantly lower in comparison to dioxins obtained from food, air, and soil. Consequently, the risk of dioxin exposure from these products is virtually non-existent.

Shyamala Mani and Satpal Singh [85, 86] studied Municipal Solid Waste Management (MSWM) and concluded that the massive amounts of garbage produced, along with health and environmental concerns and scientific disposal challenges. India's Ministry of Environment, Forestry, and Climate Change and the Ministry of Urban Development have adopted policies and activities to improve MSWM in India. The Ministry of Environment issued the Municipal Solid Waste Management Rules in 2000 and Ministry of Urban Development has published a draft manual on Municipal Solid Waste Management to help cities and towns plan and operate an effective waste management system.

2.15 Development of Eco-friendly Sanitary Napkin

An investigation on low-cost sanitary napkins was conducted by combination of three-layer and four-layer models as a prototype. Prototypes A and B have the cotton inner core, and prototype C has the recycled paper inner core. Grading system was considered to explore the operations of pads from the perspective of absorbance per cost. It was found that Prototype C performed better with 2.33/ZAR than Prototype A, 0.36/ZAR, and Prototype B, 2.09/ZAR.

Improving sanitary napkins using flax carding waste with antimicrobial efficiency was studied. The absorbent layer was made of Linum usitatissimum, the wasted fibre, and the main sheet was coated with the methanolic extract of Aloe vera. Samples had been tested for antimicrobial properties. An eco-friendly sanitary napkin using biodegradable resources was introduced. The needle-punching wool fibre in cotton was treated as the top sheet. They combined absorbent core layers using sandwiching methods like tremendous penetrable polymer sheets with cotton, bamboo, and their combination with a barrier layer containing low-density biodegradable polyethylene. The outcome has stated that using bamboo core with an indicia finish has given better performance.

An environmental-free sound biopolymer was studied on the menstrual hygiene of rural women. The analysis was carried out on cotton, viscose, wood pulp, sodium alginate, and cellulose, in different ratios at the absorbent layer with neem extract coating on the non-woven fabric that worked against the staphylococcus aureus and E. Coli. The results showed that the integration of sodium and cellulose is the best absorbent polymer. The study of design of menstrual absorbents was studied using biodegradable absorbents like cotton, linen, and bamboo to test the absorption rate stated that bamboo achieved a better absorption index of 7.86, than 0.84 contributions to cotton and 1.57 contributions to linen.

Using cotton and banana fibres, a cost-efficacy with biodegradable characteristics was studied. The multi-layered model of the specified sanitary napkins was developed to test the banana fibre wrapped with cotton and muslin cloth. The whole setup of the canvas has yielded no adverse effects on the village women. The napkins were treated with Aloe Vera and Tulsi extract against E. coli. A low-cost polyester microfiber pad was designed and explored for poor women. It was designed with the Johnson & Johnson reusable sanitary pads base obtained from polyester microfiber materials. A similar author has redesigned an ultra-thin microfiber sanitary pad using Super Absorbent Fibre (SAF) and viscose fibre blends.

2.16 Functional Finishes for Sanitary Napkins

Adopting a hygienic lifestyle proliferates and attracts consumers with increasing health and environmental problems. The consumer's expectation of textiles related to hygienic functionality is also demanding specifically for menstrual hygiene. The comfort of the clothes relies on the heat and moisture transportation between the body and the environment. The association occurs via a microclimate interface in the garment and the first sheet of clothing. Integrating with the new technologies, the different forms of fabrics were tried, tested, and executed.

Medicinal plants are the most comprehensive source employed with active compounds that intend to provide pharmacological and physiological functions for various ailments. Several natural products with the design of novel drugs were executed with standardized plant extracts. The research on plant sources with different antimicrobial compounds is studied for alternative healthcare systems, which is dictated as an ethno medicinal field. As per the standards of the World Health Organization (WHO), therapeutic herbs play a vital part in dealing drugs.

The significance of normal antioxidants such as flavonoids, tannins, and phenols was studied to prevent natural diseases and promote health. The presence of phenolic compounds uses biological plant synthesis to enhance the properties of antioxidants, anticarcinogens, and anti-inflammation. Since the plants are rich in phytochemicals, they are suitable for various infections and diseases. A similar study on the efficiency of phenolic content using a UV spectrophotometer was conducted. Curcuma longa’s leaf contains extraction of flavonoids, phenols, and glycosides, which are rich sources of antimicrobial properties. The study was profoundly done to enhance the property of antimicrobial activities. The ethanol extract from C. longa leaves holds better antimicrobial properties, which was proved.

The efficacy of Aloe Barbedensis, an antibacterial agent, has been studied to enhance the positive and negative bacteria rates. A similar study studied the leaf components containing saponin. The methanol extract from Indigofera was studied to find the phenol and tannin content. A healthy measure of the sanitary napkin is required to cope with the menstrual cycle. The comfortability of the sanitary napkin was studied using microclimate constraints between napkin and skin. The sultriness and discomfort during menstruation are mostly experienced. Most women are subjected to vulvovaginal infections like candida albicans.

The discomfort from napkins gets decreased by free water flow. The area around the entrance of the vagina is made of epithelial tissues called the vulva region. This tissue differs from other human body regions because of its structure, occlusion, hydration and susceptibility to friction. Similar to other epithelial tissues, the vulva also protects the vagina from harmful microbes through defence cells. However, the lack of ventilation, warm environments, minor injuries due to friction between the clothes and the skin favour microorganism multiplication. This becomes more serious when the wearer uses underwear, panty liners or sanitary napkins made of synthetic materials, as they increase the temperature and pH of the vulva region, causing skin infections such as irritation, soreness, redness and swelling in the vaginal area.

2.17 Harmonized System of Nomenclature (HSN)

The Harmonised System (HS) is a globally recognised benchmark for categorising various products to facilitate tracking international trade information. This categorization frequently determines the tax rate that authorities must impose and the incentives offered for various items in domestic and international markets. In India, people refer to the HS codes as HSN codes. The HSN coding system categorises products, employing 8-digit codes and corresponding descriptions. "ITC-HS codes" is an abbreviation for Indian Trade Classification or Indian Tariff Code. The ITC-HSN codes further divide the 21 divisions into 99 chapters. Furthermore, the classification of chapters includes headings, subheadings, and tariff items as shown in Fig. 2.29.

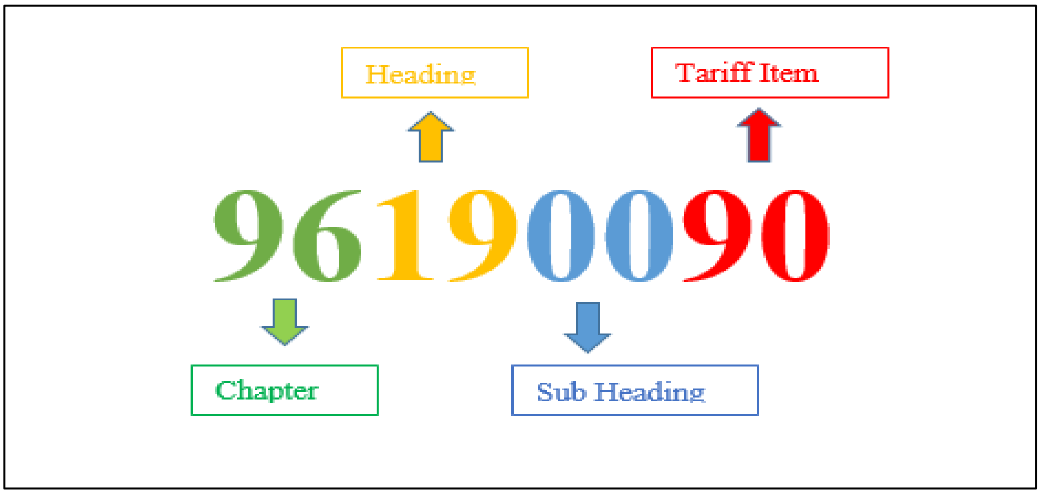


Fig. 2.29 Representation of 8-digit HSN code

2.18 India’s Trade of Sanitary Napkin

The sanitary napkin segment consistently recorded a trade deficit throughout the decade. Table 2.5 depicts the India’s annual export and import along with annual growth from year 2013 to year 2022. Over the last ten years, India's Sanitary Napkin sector has recorded a cumulative export of US$ 82,881 (000’s) and a total import US$ 1,77,406 (000’s). The annual exports have significantly amplified in this period, rising from US$3,347 (000’s) to US$16,511 (000’s), with a compound annual growth rate (CAGR) of 16%. During the same time frame, annual imports increased from US$ 13,241 (000’s) to US$ 22,930 (000’s), with 6% CAGR.

The value of India's exports and imports in the 2022 period for this particular segment amounted to US$ 16,511 (000’s) and US$ 22,930 (000’s), respectively. The yearly trade deficit has decreased over the past ten years, from 9,894 thousand dollars in 2013 to 6,419 (000’s) in 2022, primarily due to a higher increase in exports than imports.

Table 2.6 shows India’s Import of sanitary napkin from global market in last 5 years (year 2018-2022). Fig. 2.30 shows India’s import of sanitary napkin from top 5 countries from 2081 to 2022. It can be observed that China is the largest exporter of sanitary napkin goods to India from the year 2018 to year 2022. Its share has increased from 33% in 2018 to 58% in 2022. India imported total sanitary napkins worth about 23,000 US $ out of which China supplied major portion worth about 13,000 US $. Other Asian countries viz. Thailand and Myanmar supplied worth 3,400 and 1,300 US $; and Belgium supplied worth 1300 US $ and Poland supplied about worth 600 US $. According to 2022 data India’s Meditech market demand of about 60% is fulfilled from the imports from these five countries. This shows there is a great potential especially for production of sanitary napkins including other health and hygiene textiles at home.

As shown in Table. 2.7, Nepal is the largest importer of sanitary napkins, with a share of 32% from India. Its yearly portion of India’s exports has continued at 40% to 45% in the last five years. Nepal, Bhutan, Bangladesh, Congo, and Poland are the remaining bulk importers from India. Exports to the top five countries are around 35%. Fig. 2.31 shows India’s export of sanitary napkin to top 5 countries from 2081 to 2022.

Table 2.5 India's export and import of sanitary napkins of last 10 years (*1000 US$)

Sr. No.	**Year**	**Export**	**Annual growth (%)**	**Import**	**Annual growth (%)**	**Trade status**	**(Export - Import)**
1	2013	3,347		13,241		-9,894	
2	2014	4,845	45	15,556	17	-10,711	
3	2015	3,387	-30	15,197	-2	-11,810	
4	2016	5,990	77	15,584	3	-9,594	
5	2017	6,239	4	19,450	25	-13,211	Deficit
6	2018	7,640	22	20,890	7	-13,250	
7	2019	9,682	27	14,932	-29	-5,250	
8	2020	10,863	12	15,086	1	-4,223	
9	2021	14,377	32	24,540	63	-10,163	
10	2022	16,511	15	22,930	-7	-6,419	
	Total	82,881		1,77,406		-94,525	
	CAGR	17%		6%			

Source: Calculations based on data from www.trademap.org

Table 2.6 India's import of sanitary napkin from top countries (*1000 US $)

Exporters	**2018**	**2019**	**2020**	**2021**	**2022**
World	20,890	14,932	15,086	24,540	22,930
China	6,993	6,845	6,568	10,419	13,196
Thailand	4,053	1,535	1,595	4,549	3,410
Belgium	3	41	564	1,390	2,476
Myanmar	0	0			1,314
Poland	210	627	213	441	637

Source: Calculations based on data from www.trademap.org

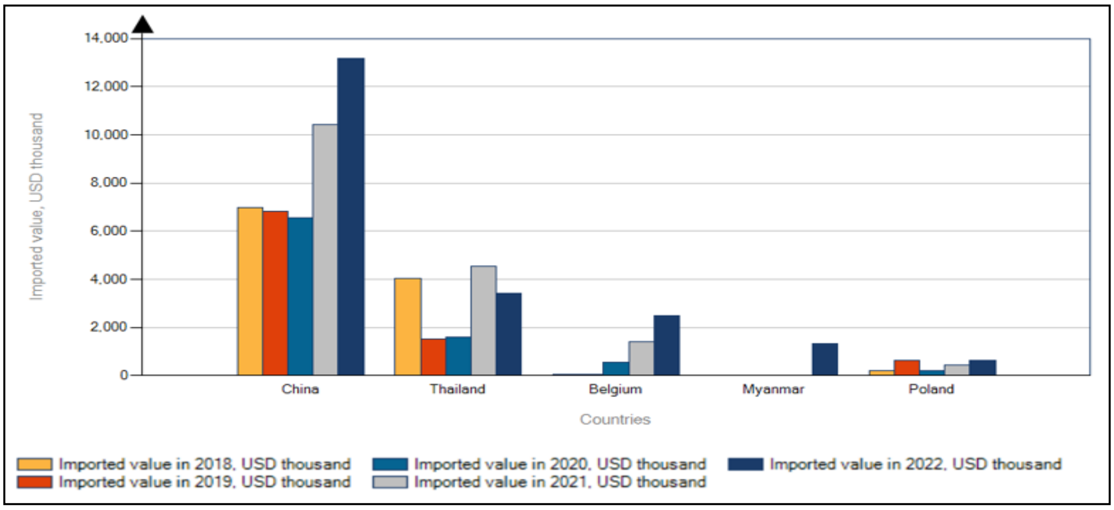


Fig. 2.30 India's import of sanitary napkin from top 5 countries (2018-2022) (*1000 US $)

Table 2.7 India's export of sanitary napkin to top 5 countries (*1000 US $)

Importers	2018	2019	2020	2021	2022
World	7,640	9,682	10,863	14,377	16,511
Nepal	3,307	4579	5,498	7,460	5,210
Bhutan	483	662	737	856	956
Bangladesh	997	1,232	650	785	791
Congo	0	1	4	131	775
Tanzania	34	5	16	178	696

Source: Calculations based on data from www.trademap.org

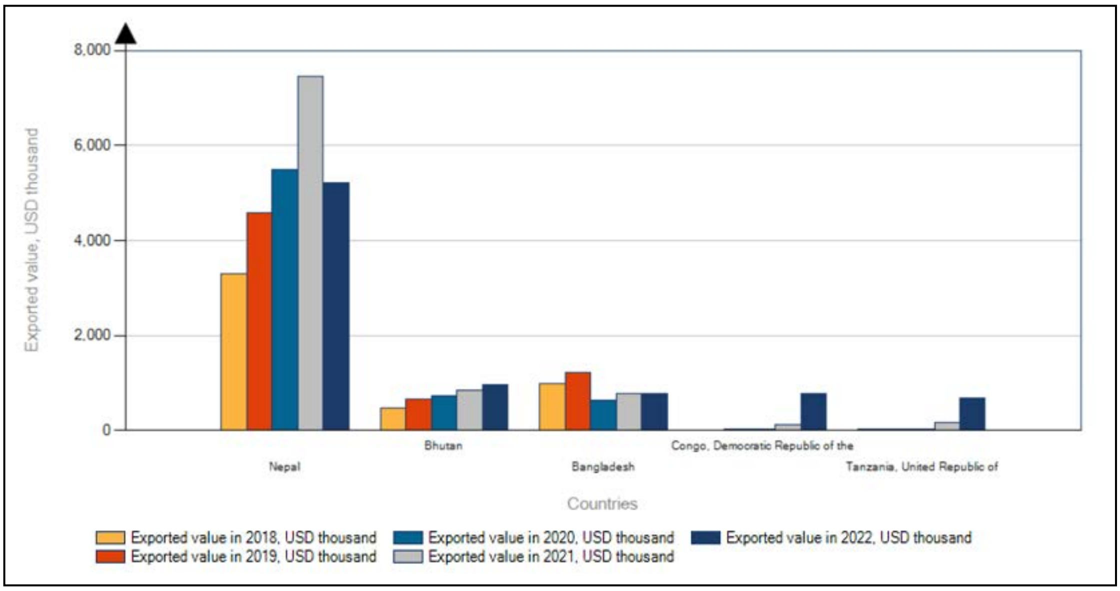


Fig. 2.31 India's export of sanitary napkin to top 5 countries (2018-2022) (*1000 US $)

2.19 International Trade of Napkin's Materials

2.19.1 Spun-bond Nonwovens

The Indian market recorded an average export value of 165 million US $ over 5 years period from year 2018 to 2022 for spun-bond nonwoven textiles and made-ups. It was 158 million US $ in the year 2022. As compared to immediate previous year it's a decline of 30%. India exports spun-bond nonwovens more than 55% of the global value only to the US which is one of the main developed countries (Table 2.8). The other main market has been UAE, Qatar and UK. As compared to other countries India's average export to global market is marginal having only a market share of about 1%. Looking to the global demand of nonwoven fabrics

Table 2.8 India’s export of spun-bond nonwovens (* 1000 US$)

Importers	2018	2019	2020	2021	2022
World	1,36,392	1,32,238	1,74,733	2,26,650	1,58,079
USA	55,680	65,995	83,372	1,28,186	89,387
UAE	6,618	4,366	5,423	6,935	10343
Qatar	4,209	3,635	4,240	7,171	7,864
UK	7,525	8,886	9,713	8,712	4,500

Source: Calculations based on data from www.trademap.org

India is having good potential to increase the export in coming years as especially numbers of countries are looking for the option of China due to post-covide19 situations. The export amount proportion to United States of America is 89 million (56%), United Arab Emirates is $10 million (6.3%), and Qatar is $7.8 million (4.9%) and UK is 4.5 million (2.8%). Fig. 2.32 shows India’s export of spun-bond nonwovens to top 5 countries from 2018-2022.

Table 2.9 shows global market for spun bond nonwoven fabric a total export value of $18,584 million in 2022. China, Germany, and USA are the leading global exporters of spun-bond nonwoven fabric. India's global export share is less than 1% of the total export value.

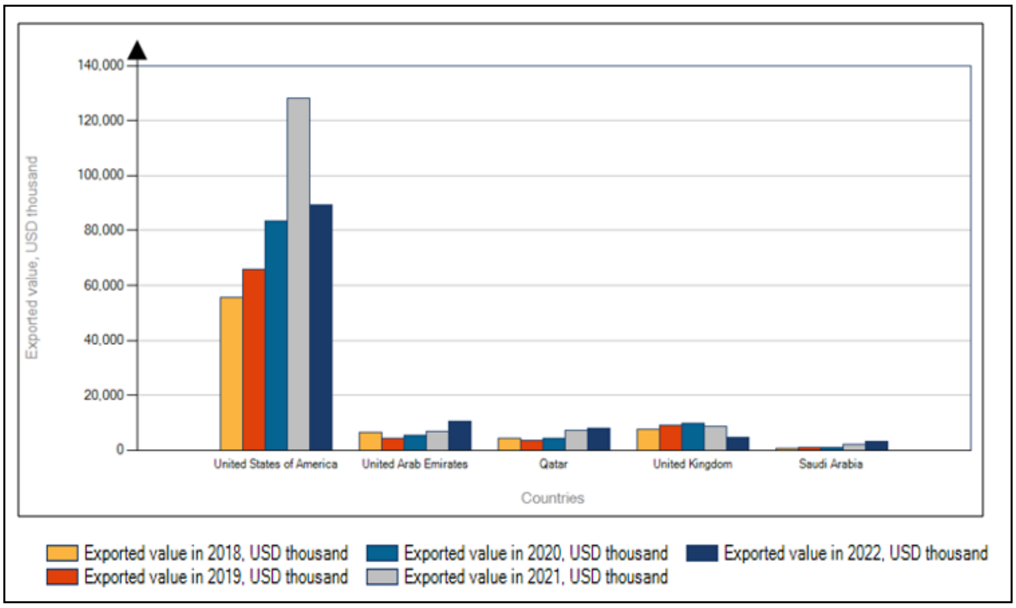


Fig. 2.32 India’s export of spun-bond nonwovens to top 5 countries (*1000 US $)

Table 2.9 Global export of Spun-bond Nonwovens to various countries (* 1000 US$)

Importers	2018	2019	2020	2021	2022
World	1,66,15,585	1,64,21,922	1,89,80,831	2,01,41,353	1,85,84,603
China	29,57,746	31,10,469	50,47,782	45,41,943	39,90,904
Germany	21,56,361	20,91,146	20,87,774	23,59,680	21,15,429
USA	19,06,076	18,59,089	19,00,621	20,49,899	19,73,331
Italy	12,90,053	12,54,105	12,30,069	14,75,479	13,81,232

Source: Calculations based on data from www.trademap.org

China is the world's leading exporter of nonwoven fabrics, accounting for approximately one-fifth of global exports. In 2022, Chinese exports of nonwovens reached $3,990 million, representing 20% of global spun-bond nonwoven exports. China is the largest exporter of nonwoven fabrics and has the highest growth rate in nonwoven production.

The Chinese industry currently focuses on major portion of the technical textiles production to the export purpose. Increasing exports is a top goal for the government, and big investments are being made to speed up research and development in the technical textiles industry. This will make the Chinese industry more competitive on a global scale. The Chinese government is putting lot of effort to grow the export of fabrics especially used to make medical textiles.

The import value of the Spun bond nonwoven in 2022 was USD 233 million, indicating a 7% decline in dollar terms compared to the same period in 2021, as presented in Table 2.10. The export volume has decreased from $252 million to $233 million. In India, numerous manufacturing lines have emerged producing the same product. The level of dependence on foreign countries has now diminished. India imports most of its nonwoven fabric from China, Japan, Thailand and Malaysia. Fig. 2.33 shows India’s import of sanitary napkin of top five countries from 2018 to 2022.

Table 2.10 India's import of spun-bond nonwoven from global market (* 1000 US$)

Exporters	2018	2019	2020	2021	2022
World	2,47,751	2,33,786	1,91,448	2,51,777	2,33,825
China	96,315	83,656	73,588	98,818	93,024
Japan	18,424	17,711	15,416	28,611	27,171
Thailand	12,527	14,378	10,598	18,079	21,168
Malaysia	15,246	10,354	12,517	16,053	13,696

Source: Calculations based on data from www.trademap.org Unit: US Dollar thousand

Table 2.11 reveals that the aggregate value of imports in the global market amounts to $18,129 million. The United States, Germany, China, and Japan collectively contribute more than 29% of this total. The United States is the leading worldwide importer, with an import value of over $2,106 million. It can be seen that India's import value is more significant than its export data from 2018 to 2022. Compared with the worldwide market, the world export data shows a slight increase compared to the import data.

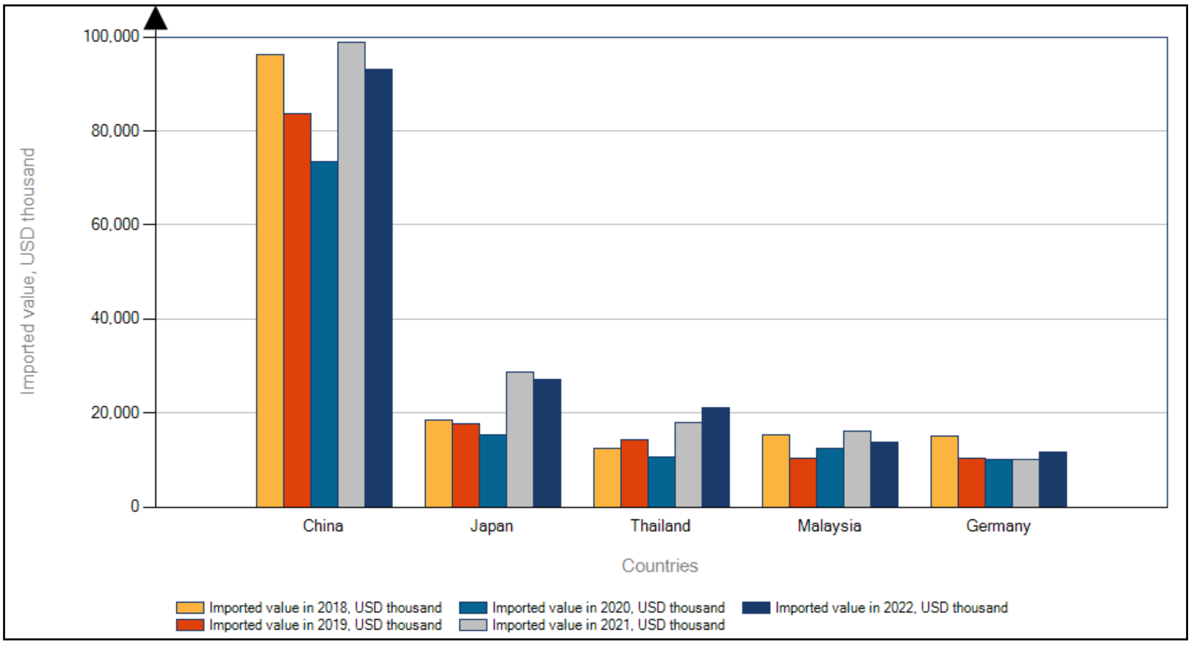


Fig. 2.33 India's import of spun-bond nonwovens from top of last 5 years (*1000 US $)

Table 2.11 World import of spun-bond nonwoven from global market (* 1000 US$)

Exporters	2018	2019	2020	2021	2022
World	1,56,31,687	1,53,71,139	1,76,94,459	1,91,25,869	1,81,29,008
USA	15,36,017	15,62,275	20,90,814	22,50,678	21,06,571
Germany	11,62,038	11,20,741	11,73,671	14,23,921	13,18,645
China	9,12,052	8,42,150	11,22,116	10,56,302	9,1 7,793
Japan	8,58,939	8,59,672	8,85,875	8,74,761	8,35,430

Source: Calculations based on data from www.trademap.org

2.19.2 Organic Cotton

Chemical fertilisers and pesticides are not used in the production of organic cotton. The organic farming works at the grass roots level to keep the earth's ability to reproduce and grow healthy food that is resistant to diseases. India has a lot of potential to produce all kinds of organic foods because of different types of terrain and climates. The practice of organic farming has been done for a long time in some parts of the country. This is good for organic farmers who want to get into a market that is slowly growing both at home and abroad. India is the highest producer contributing almost half of the global production hence India dominates in the organic cotton exports globally, with a market share of 38% and an export value of $78 million in 2022 Table 2.12. The Bangladesh has 30%, the Portugal has 21% in 2022, Guatemala has 15%, and Korea has 9% in 2022, and 4% are mainly supplied by Egypt.

Fig. 2.34 shows the total production data of organic cotton from year 2015 to 2020. In the 2019/20 harvest year, 229,280 farmers cultivated 249,153 tons of organic cotton fibre on 588,425 hectares of certified organic land in 21 countries. Related to the preceding year, there has been 3% increase in the number of farmers, 4% gain in fibre volume, a 41% expansion in land area, and the inclusion of twofold more countries producing organic cotton. It can be seen that seven countries account for almost 95% in the production of organic cotton. India accounted for about 50% of the output, while China and Kyrgyzstan each contributed 12%,

Table 2.12 India Export of organic cotton to global market (* 1000 US$)

Importers	2018	2019	2020	2021	2022
World	95,003	66,351	57,919	1,26,472	78,526
Bangladesh	10,961	4,971	12,348	34,030	23,389
Portugal	23,110	18,478	13,524	30,750	16,480
Guatemala	6,064	7,820	7,125	9,918	11,844
Korea	10,531	8,893	5,605	7,526	6,724

	Organic Cotton Fiber (tonnes)	Fiber Year-on-Year	Share of global organic cotton production
Global	249,153	3.9%	100%
India	124,244	1.3%	49.8%
China	30,589	-25.8%	12.3%
Kyrgyzstan	29,415	24.4%	11.8%
Turkey	24,288	6.3%	9.7%
Tanzania	11,285	113.7%	4.5%
Tajikistan	10,471	-14.0%	4.2%
U.S.	6,913	33.9%	2.8%

Fig 2.34 Organic cotton production of various countries (tons)

Fig. 2.35 shows global production share of organic cotton of various countries. According to The Roundup.org, India leads the world in organic cotton production 50 %, followed by China (12%), Kyrgyzstan (12%), and Turkey (10%) and Tanzania (5%).

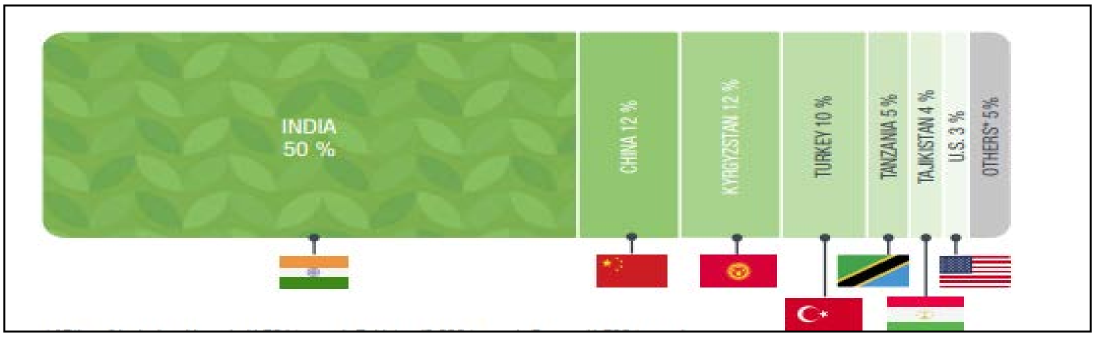


Fig. 2.35 Global production share of organic cotton of various countries

Table 2.13 World Export of organic cotton to global market (* 1000 US$)

Importers	2018	2019	2020	2021	2022
World	3,68,563	3,11,115	2,01,089	3,15,039	2,77,268
Pakistan	1,32,610	1,21,640	52,910	75,645	92,373
India	97,355	68,444	59,124	1,29,897	78,805
Uzbekistan	16,226	18,284	13,331	26,138	29,509
China	28,750	21,587	16,128	18,595	15,617

Source: Calculations based on data from www.trademap.org

The global market for Organic Cotton had a total export value of $2.77 million in 2022, as indicated in Table 2.13. Pakistan, India, Uzbekistan, and China are prominent global suppliers of Organic Cotton. India has a substantial portion of the worldwide export market, representing more than 40% of the whole export value. In 2019, 10 enterprises distinguished themselves in the global market for their use of organic cotton. The ranking of these enterprises was determined by evaluating their exemplary management practices, encompassing criteria such as risk evaluation, openness, investment, goal establishment, impact measurement, and utilisation rate of "preferred cotton". The firms ranked in the top 10, in descending order, were H&M, C&A, Inditex, Aldi Group, Tchibo, Nike, AB Lindex, Varner, Bestseller, and Stanley & Stella. The following are the top 10 organic trade companies that satisfy the identical criteria: Boll & Branch, Naturaline, Dibella, Cotonea, Dedicated Sweden, ARMEDANGELS, Knowledge Cotton Apparel, Coyuchi, Veja, and Continental Cloth [87].

The worldwide market for Organic Cotton saw a cumulative import value of $2.74 million in 2022 (Table 2.14). Turkey, Portugal, Bangladesh, and China are the largest importers of organic cotton in the global market. Organic cotton products imported under HTS Chapter 52 of have experienced recent expansion. Prior to 2020, the U.S consistently imported between 1,300 MT and 1,700 MT annually. Historically, the largest country of origin for U.S. organic chapter 52 imports has been India, which shipped 850 MT to the U.S. over 2019, followed by Pakistan which shipped 340 MT to the U.S. over the same year. Over 2020, however, U.S. imports of organic chapter 52 products increased substantially, led by an expansion in organic fabric and yarn imports from India, and organic cotton imports from Pakistan [88].

Table 2.14 World Import of organic cotton from global market (* 1000 US$)

Exporters	2018	2019	2020	2021	2022
World	3,16,771	2,62,694	2,08,131	2,96,215	2,74,863
Turkey	43,432	48,794	36,782	48,660	54,577
Portugal	40,316	30,997	24,452	43,586	40,968
Bangladesh	31,000	21,652	19,213	45,676	40,699
China	62,844	35,750	23,001	43,424	17,624

U.S. organic fabric imports reached 1,400 MT over 2020, with 780 MT imported from India. Organic yarn imports reached 930 MT over 2020, with 490 MT imported from India. Finally, organic cotton imports reached 690 MT, with 310 MT imported from Pakistan. In total, U.S. organic imports of organic chapter 52 products reached 3,000 MT over 2020 since 2016

19.3 Silk Waste

India cultivates four distinct varieties of ordinary silk: Mulberry, Eri, Tasar, and Muga. The nation manufactures various textile products, including silk garments, textiles, Equipments, covers and shawls using the raw materials [89]. The primary commodity shipped to China has been silk waste, accounting for 92.53% of the exported goods by India (Table 2.15).

India supply to the silk waste to the other country is Italy, Germany, UK and Bangladesh. India ranks as the world's second-largest silk producer. The sericulture industry in the country provides employment to around 9.2 million individuals residing in rural and semi-urban regions, as of the year 2022-23. This sector is a significant contributor to the country's foreign exchange earnings. Sericulture operations in India are distributed among 52,360 communities [89, 90]. The total quantity of silk waste that India exported in 2022 was $19.4 million, which placed it in the third position among the most prominent exporters of silk waste on a global scale (Fig. 2.36). During the 2022 year, silk waste was classified as the 658th most valuable item that India exported. The most important countries to India’s exports of silk waste has been China ($19.4 MN), Italy ($1.5 MN), Malaysia $96 (000’s), UK $83 (000’s), and the Bangladesh ($71.06 (000’s) [90]. In 2022, India ranked 16 among the world's top importers of silk waste, with imports valued at $1,0310 (000’s). Silk waste was positioned at the 1116th rank in terms of income among other imported products in India (Table 2.16).

Table 2.15 India's export of silk waste to global market (* 1000 US$)

Importers	2018	2019	2020	2021	2022
World	19,160	14,850	18,423	30211	19,485
China	12,909	12,445	16,568	27781	17,544
Italy	884	1145	1683	2048	1583
Germany	9	15	0	7	96
UK	109	70	39	72	83
Bangladesh	0	20	22	49	71

Source: Calculations based on data from www.trademap.org

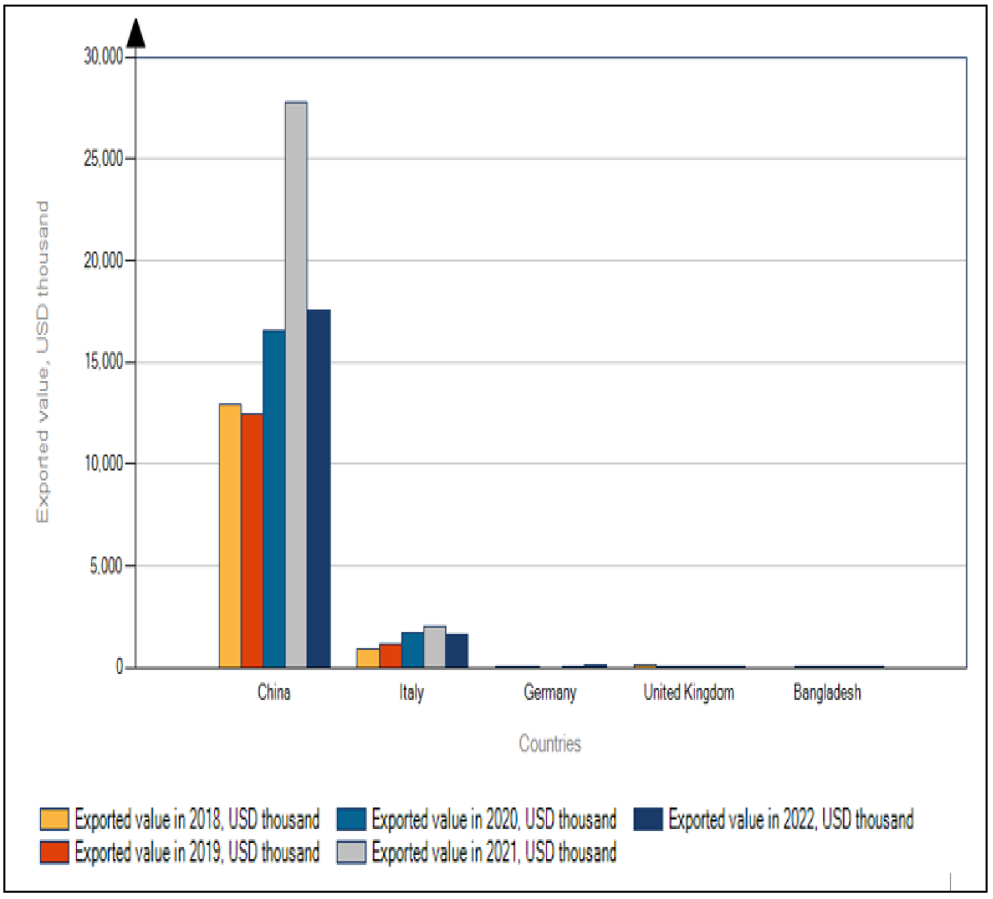


Fig. 2.36 India export of silk waste of last 5 years (*1000 US $)

Table 2.16 India's import of silk waste from global market (* 1000 US$)

Exporters	2018	2019	2020	2021	2022
World	2,865	4,877	1,081	622	1,031
China	2,865	4,571	1,060	549	1,004
Indonesia	0	0	0	0	13
Japan	0	0	0	0	13
Bangladesh	0	0	1	1	1
Georgia	0	0	0	72	0

India mostly imports silk waste from the following countries: china ($1031 (000's)), Indonesia $13(000's), Japan $17(000's), Bangladesh $1 (000's), and Georgia (Fig. 2.37) [90]. Table 2.17 encompasses world export of silk waste to global market in last 5 years.

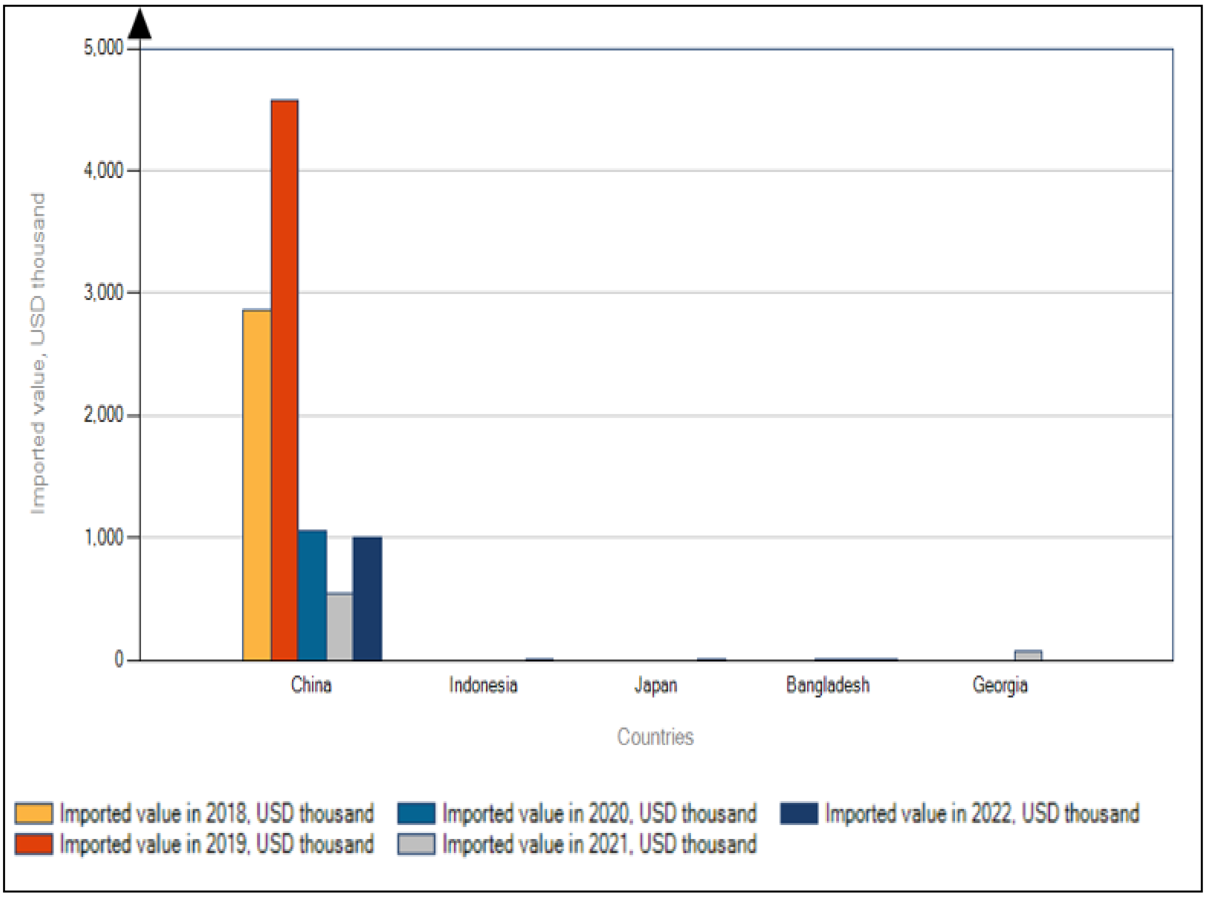


Fig. 2.37 India Import of silk waste of last 5 years (*1000 US $)

Table 2.17 World export of silk waste to global market (* 1000 US$)

Importers	2018	2019	2020	2021	2022
World	99,721	88,972	91,623	1,20,833	1,02,083
China	41,052	31,186	22,687	33,287	37,924
Uzbekistan	19,278	27,239	37,020	36,070	20,966
India	19,160	14,850	18,423	30,211	19,485
Germany	9,922	6,115	5,509	6,959	6,653
Italy	5,181	2,289	2,569	3,172	4,235

Table 2.18 demonstrates that the majority of the world's imports of silk waste come from China, with $102 Million, Uzbekistan, with $37 Million, India, with $19 Million, Germany, with $6.6 Million, and Italy, with $4.23 Million [90].

Table 2.18 World import of silk waste from global market (* 1000 US$)

Exporters	2018	2019	2020	2021	2022
World	99,721	88,972	91,623	1,20,833	1,02,083
China	41,052	31,186	22,687	33,287	37,924
Uzbekistan	19,278	27,239	37,020	36,070	20,966
India	19,160	14,850	18,423	30,211	19,485
Germany	9,922	6,115	5,509	6,959	6,653
Italy	5,181	2,289	2,569	3,172	4,235

2.19.4 Perforated Poly (PE) Film

Sanitary napkins use perforated poly-film, a polyethylene film, as a top sheet. It absorbs menstrual fluid and passes it to the inner absorbent layer. It is mainly used as the top sheet of sanitary napkin based due to its breathable and non-toxic, odourless and light properties. Table 2.19 displays India’s exports of perforated poly film over last 5 years. The export amount proportion to the United States of America is 1349 million (16.84%), Italy is $62 million (4.63%), UK is $62.4 million (4.9%), and UAE is 52 million (2.8%).

Table 2.19 India’s export of Poly-PE film to global market (* 1000 US$)

Importers	2018	2019	2020	2021	2022
World	10,17,620	10,04,978	10,16,329	13,53,510	13,49,685
USA	1,17,640	1,22,495	1,41,141	2,17,970	2,27,271
Italy	48,692	41,272	32,970	60163	62,452
UK	25,452	27,769	35,275	50,708	57,373
UAE	42,151	44,600	41,971	48,125	52,763

Table 2.20 shows India’s import from global market of Poly PE Film. The share of total import to the China is (55.94%), while the proportion to Hongkong is (12.98%), exports to the Ireland are $62.4 million (10%), and exports to the Thailand 114 million (8.378%). Table 2.24 presents the data regarding India's import of perforated poly throughout the course of the past five years.

Table 2.20 India’s import of Poly-PE film from global market (* 1000 US$)

Exporters	2018	2019	2020	2021	2022
World	11,38,519	11,84,850	9,84,897	15,61,448	18,75,981
China	4,77,817	4,87,963	3,85,485	6,45,862	7,55,058
HK	61,490	1,02,920	98,589	1,47,958	1,75,150
Ireland	466	720	530	38,855	1,34,812
Thailand	73,151	75,464	67,760	99,182	1,14,073

2.19.5 Wood Pulp

Wood pulp fluff is a soft and absorbent material made from 100% Nordic spruce and pine. Our fluff pulp, Natura Fluff, is versatile and can be incorporated into various applications and products that are likely already integral to your everyday life. It excels in hygiene products like baby diapers, feminine care, and adult incontinence protection products. It is also well-suited for use in air-laid nonwovens such as napkins, table-tops, food pads, and various medical sector products. Based on the data provided in Table 2.21, it seems unlikely that

Table 2.21 India's export of pulp to global market (* 1000 US$)

Exporters	2018	2019	2020	2021	2022
World	5	1,537	303	6	0
Germany	0	0	0	0	0
Bhutan	0	0	0	3	0
Nepal	1	0	36	3	0
Rwanda	0	0	7	0	0

India can participate in the wood pulp trade. As shown in Table 2.22, in global market, wood pulp majority import from the USA, Canada, Finland and Sweden. The United States exported around 7.98 million metric tons of wood pulp in 2022, and imported 6.95 metric tons. The North American country accounted for roughly 11 percent of global wood pulp exports in 2021, making it the third-largest wood pulp exporter worldwide, behind Brazil and Canada [91, 92]. In global market, pulp import form the china, USA, Italy and Germany as shown in Fig. 2.39 in global market. India majority import the wood pulp form the, USA, Chile, Canada, Sweden and Finland (Table 2.23) as well as globally, import form the same country (Table 2.24). This is because India lacks the necessary infrastructure to produce pulp. Wood pulp tree (pine tree), grow in cold environment country only i.e. USA, Canada, Sweden and Finland. According to Fig. 2.38, India is currently engaged in the trade of wood pulp with UAE, but it is not exporting to any other country. Fig. 2.39 shows India's import of wood pulp of last 5 years.

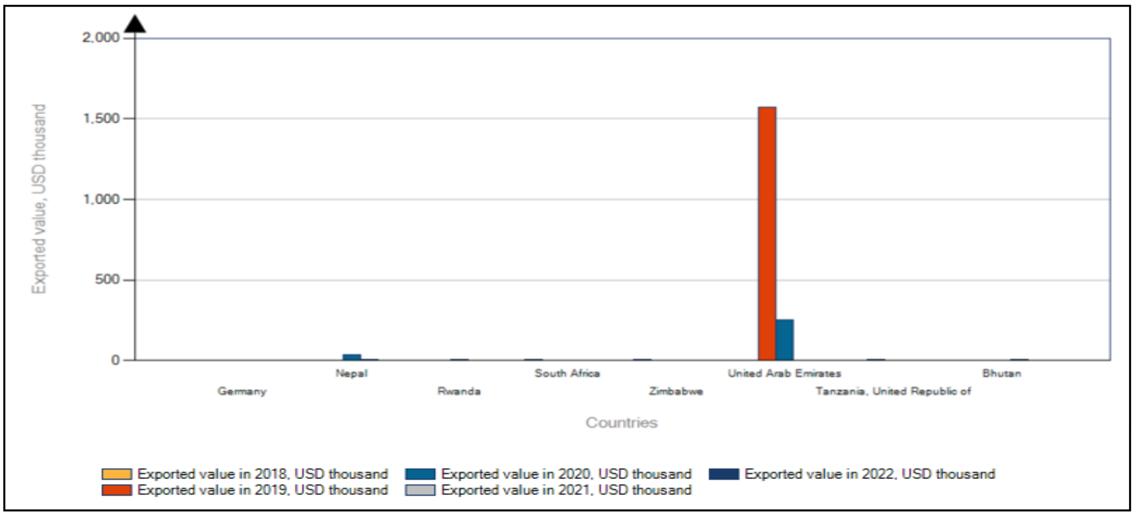


Fig. 2.38 India export of wood pulp of last 5 years (*1000 US $)

Table 2.22 World export of pulp to global market (* 1000 US$)

Importers	2018	2019	2020	2021	2022
World	1,83,51,928	1,58,04,090	1,34,85,821	1,65,17,267	1,91,15,169
USA	42,41,295	40,80,453	36,88,553	43,27,666	54,77,986
Canada	45,38,270	36,03,520	29,59,323	36,51,409	37,91,211
Finland	24,62,771	19,83,592	15,74,107	21,82,513	25,23,708
Sweden	19,39,108	19,26,824	18,26,777	22,89,869	22,77,496

Table 2.23 India's import of pulp from global market (* 1000 US$)

Exporters	2018	2019	2020	2021	2022
World	2,13,797	1,88,784	1,67,147	2,30,672	3,63,084
USA	97,616	1,05,906	1,06,835	1,43,483	2,24,458
Chile	39,703	16,498	17,912	28,603	57,068
Canada	38,303	36,201	21,807	23,330	33,413
Sweden	10,696	8,021	7,261	8,774	12,780

Table 2.24 World's import of pulp from global market (*1000 US $)

Exporters	2018	2019	2020	2021	2022
World	1,89,84,881	1,64,33,627	1,41,28,679	1,72,51,398	1,96,51,629
China	67,89,380	58,60,928	51,11,571	66,99,409	64,68,339
USA	15,77,022	15,03,917	15,03,305	18,71,809	21,73,497
Italy	10,30,711	8,68,069	6,22,470	7,78,599	9,71,519
Germany	9,82,812	9,16,706	7,39,114	8,79,319	9,68,983

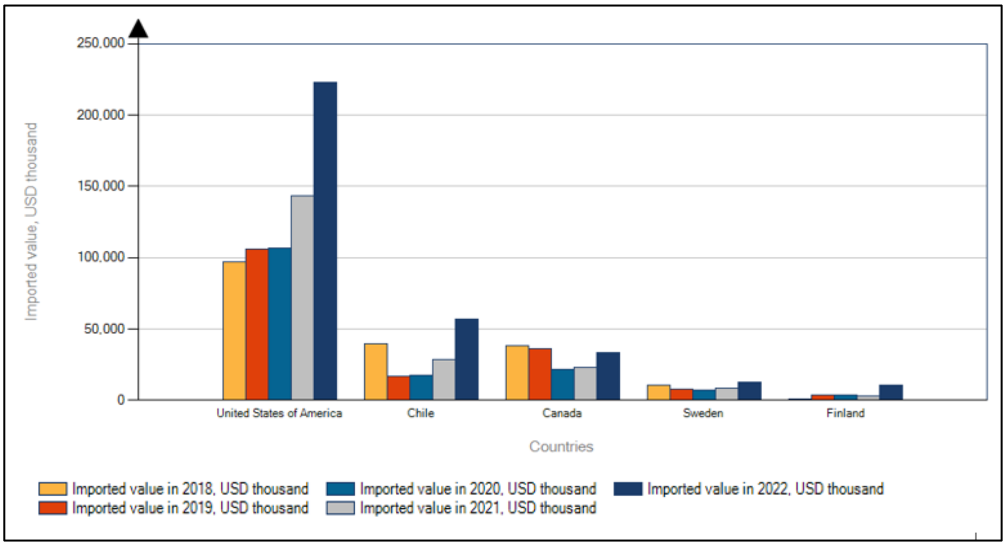


Fig. 2.39 India's import of wood pulp of last 5 years (*1000 US $)

2.19.6 Super Absorbable Polymer (SAP)

A highly advanced polymer, commonly referred to as slush powder, has the remarkable ability to absorb water up to 300 times its original mass. Because of their exceptional water absorption properties, they are widely used in gels, and the cross-linkers in SAP help them effectively retain water. High absorbent capacity is often preferred over low-density cross-linkers in SAP. These SAPs are also great for creating a more malleable, adhesive gel.

Table 2.25 India Export to Global Market - SAP (*1000 US $)

Importers	2018	2019	2020	2021	2022
World	77,352	85,434	98,501	2,68,104	1,98,264
Bangladesh	11,196	11577	12,273	23,470	23,356
Argentina	88	125	517	19,678	20,124
Nepal	11,339	9,785	7,794	20,829	16,194
UAE	5,347	5,631	7,058	11,290	12,993

The market is being propelled by the increasing awareness of hygiene and the growing demand for diapers in emerging economies. Furthermore, the market is influenced by an increase in the adoption of highly absorbent polymers in agricultural applications. In addition, countries with a significant number of elderly citizens, like Japan, Italy, Finland, Greece, and others, experience a substantial demand for adult diapers, leading to a significant expansion of the market. As shown in Fig. 2.40 India is export to Bangladesh, Argentina, Nepal and UAE (Table 2.25).

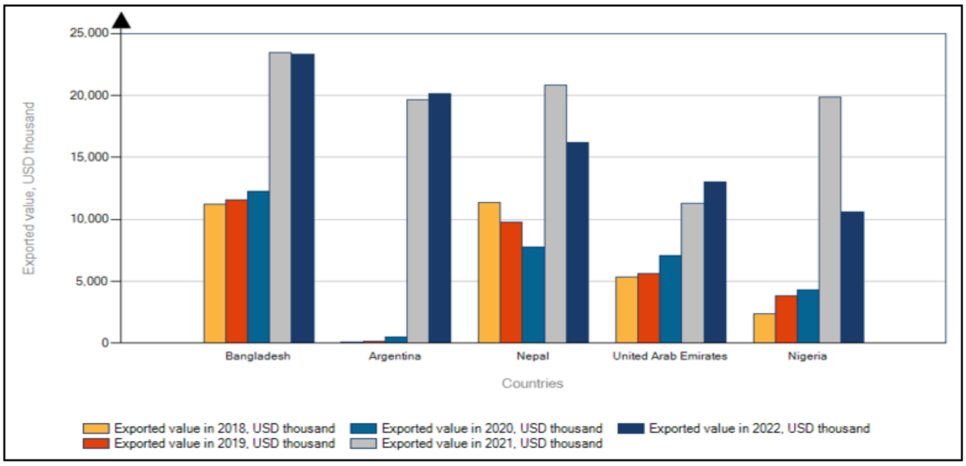


Fig. 2.40 India Export of SAP powder of last 5 years (*1000 US $)

As shown in Table 2.26, India is importing SAP powder 25% from the China, 15% form Japan, 9% form Korea and 8% form Netherland (Fig. 2.41).

Table 2.26 India Import from Global Market - SAP (*1000 US $)

Exporters	2018	2019	2020	2021	2022
World	4,71,700	4,63,742	3,07,914	4,21,345	5,25,618
China	1,81,816	1,83,621	67,694	97,745	1,32,930
Japan	64,787	59,094	39,713	55,543	76,710
Korea	35,301	32,995	23,763	36,746	46,366
Netherlands	16,415	28,758	24,050	25,053	42,199

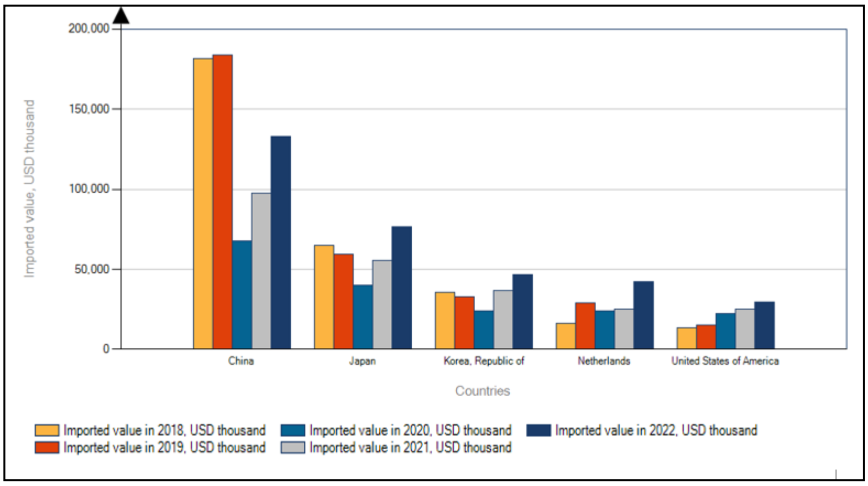


Fig. 2.41 India's import of SAP powder of last 5 years (*1000 US $)

This data of trade of all these raw materials required for the production of various health and hygiene products in general and sanitary napkins in particular shows that there is very high potential to expand the production at home. This will also increase the India's export and decreased the import in near future there by improving the economy of the country. The study under taken to improve the characteristics and performance of the sanitary napkin will definitely useful in boosting up the India’s textile industry.

The need for high-quality and environmentally friendly sanitary napkins is increasing due to women's growing awareness of hygiene and the environment, while also preserving their affordability. The objective of this project is to provide environmentally friendly and cost-effective sanitary napkins that are accessible to women of all socioeconomic backgrounds. The current study is thus centred on creating cost-effective, eco-friendly sanitary napkins that are biodegradable, while also ensuring that they meet the quality criteria set by the Bureau of Indian standards (BIS). Examining the eco-friendly biodegradable sanitary napkins beside the non-biodegradable sanitary napkins that were developed. Additionally, the study includes the analysis of the performance attributes of the created sanitary napkins. Subsequently, the performance parameters are analysed by a comparative study of different properties of the manufactured sanitary napkins.