Chapter 20
Sustainable Development in Textile Processing

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Contents

Abbreviations

BOD	Biological oxygen demand
CF	Fluorocarbon
COD	Chemical oxygen demand
DMDHEU	Dimethyl dihydroxy ethylene urea
DNA	Deoxyribonucleic acid
LOI	Limiting oxygen index
nm	Nanometer
UV	Ultraviolet

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20.1 Introduction

Due to global warming and environmental pollution, for the last 30–40 years, various researches focusing on sustainable textile processing have been conducted. Among the researches, lesser usage of water and chemicals, foam finishing, enzyme-based treatment of textiles, and different irradiation techniques are mostly the predominant topics. For the last 10–20 years, more new technologies have emerged in the research field of sustainable textile processing. Among the developed technologies, nanoparticle-formulation-based textile finishing, plasma, UV irradiation for different value additions of textiles, and use of natural biomolecule for functionalization are important (Samanta et al. 2019). In most cases, industrial textile processing requires large quantities of alkalis, acids, chlorinated bleaching agents, toxic synthetic dyes, finishing chemicals. etc. These mentioned ingredients are very toxic and are quite capable of increasing the total dissolved solids, BOD, and COD of effluent water. Some of the mostly explored synthetic dyes, especially sulfur dye and azo-based dyes, are very much toxic and have strong carcinogenic effect on any living being. Polyester textile dyeing is very costly and requires high-temperature high-pressure machine for the accomplishment of the dyeing process. Therefore, researchers are trying to replace polyester dyeing with waterless supercritical carbon-dioxide-based dyeing process. Concerning antimicrobial treatment of textile materials, chlorinated compounds, positive-charge-containing quaternary ammonium compounds, and polyhexamethylene biguanide are generally explored by textile industries (Samanta et al. 2017a). For UV-protective finishing, different dark-color high-molecular-weight compounds like phenyl salicylate, benzophenone, and benzotriazole-based chemicals are continuously and commonly used by textile industries. However, they are carcinogenic and have some irritant smell and odor. With regard to flame-retardant finishing, formaldehyde-based chemicals are more popular in the commercial sector for its outstanding durability and effectivity for flame retardancy. The phosphorus-, chlorine-, and nitrogen-based Pyrovatex, Proban, and formaldehyde resin cross-linkers are used most popularly in flame-retardant finishing of cotton textiles (Samanta et al. 2014a). Due to the difficulty in the process control and the toxicity of the treatment, very few Indian industries are running these processes. For fire retardancy of synthetic materials (polyester, nylon, acrylic. etc.), toxic halogen-based chemicals are commonly used by industries. However, use of halogens has been slowly abolished because of dioxins and furan release during processing. On the whole, most of the auxiliaries used by textile industries in textile processing have adverse effects on the environment. In the past, various steps have been taken by scientists and researchers in making eco-friendly synthetic chemicals for textile processing. Di- and tricarboxylic acids and dimethylol-dihydroxy-ethylene-urea-based cross-linkers have already been used by earlier researchers. In addition, use of larger quantity of salt during reactive dyeing, use of high alkali and hydrose in vat dyeing, sulfur dyeing, reduction clearing of polyester (hydrose and soda ash required), and color stripping from dyed fabric (hydrose required) are not eco-friendly processes. However, these are the running process in most of the textile industries in India and other Asian countries (Lal et al. 2018). All these mentioned processes adopted by textile industries discharge larger quantity of unfixed dyes, alkalis, acids, hydrose, oxidative bleaching agents, cyanide, etc. in the effluent water, and they are some of the major challenges in the sustainable processing of textiles.

A number of research groups, industries, and scientists around the world are involved in sustainable activities connected with textile processing. They are continuously trying to develop newer methodologies and process conditions for the value addition and processing of textile materials. Different groups of scientists are working on different ways to achieve the same target: sustainability. Some of them have also been adopted by textile industries. Application of various plant-based extracts (molecules) for textile coloration and functionalization; water-saving processes like plasma, UV, and electron beam irradiation; and nanomaterial-based value addition of textiles are also becoming popular and are discussed below in details.

20.2 Eco-Friendly Approaches for Making Textile Material

In order to come up with an eco-friendly textile processing, researches are being conducted in different directions. Most of the researches are based on the usage of nanomaterials and plant-based extracts. These materials are capable of replacing various synthetic materials for the value addition of textile. As minimization of the exploration of water is another important challenge, different energy- and water-saving techniques like irradiation technologies, zero-liquor processes, padding techniques, foam finishing, etc. have been developed and commercialized in some of the application areas.

20.2.1 Sustainable Textile Processing by Using Biomacromolecule

20.2.1.1 Textile Dyeing by Natural Dye

Different plant-based and animal-based biomolecules have been explored for making natural dye and also value-added textile materials. Concerning the use of natural dye, during the Vedic time period, India explored different herbal and medicinal plants for dyeing textile materials. Indeed, during that time, they have made "Ayurvastra" type textile products by using their own indigenous technologies. From the literature, it has been found that the fabric made by them has various well-being properties. However, natural dyeing was costly, and the availability of the source material was difficult. Lots of other issues like shade variations, shade limitations, and lack of wash durability were also present. In those days, only the elite class of people could wear dyed dresses. Therefore, after the emergence of synthetic dyes, natural dye processing became a big setback, and the world started to move in the synthetic direction. It was a synthetic revolution, and dyes like vat, reactive, acid, and basic became very popular in the textile industries as these dyes are capable of providing nice shades and color, with more amount of fabric in less time but with more durability. However, for the last 30 years, due to environmental challenges and government legislation, the world is trying to move towards the eco-friendly direction in every sector. Therefore, natural-dyed textiles are again in demand. Now, in this area, a major challenge for researchers is to maintain repeatability of shades, durability, etc. (Samanta et al. 2016).

Chemically, natural dyes have different alternating double bond and single bond groups. Most of them contain long chain of quinines, anthraquinones, napthaquinones, and indigoid-based chromophores. Natural dye can be extracted from various herbal sources by water or alcoholic extraction. However, in most of the cases, prior mordanting is required before application of the natural dye on the natural textile material. Generally tannic acid, alum used as mordants for coloration of textile materials with different natural dyes. Apart from it, other salts of high-valance metals like copper, chromium, iron, etc. have been used by researchers for mordanting purposes. These mordanting materials assist to hold the dye molecule and the primary –OH group of cotton cellulose by suitable chemical bridge formation. In connection to dyeing, madder, turmeric, onions, beetroot (dye from root sources), Sappan, khair, sandalwood (dye from bark sources), indigo, lemongrass (dye from leaf sources), marigold, dahlia, Tesu, Kusum (dye from flower sources), myrobalan, pomegranate rind, and Latkan (dye from fruit sources) have been explored popularly for the coloration of cotton textile materials. However, in most cases, washing durability and wet rubbing fastness are major challenging areas. Another major challenge in the natural dye sector is the limitation of shades. Only the colors yellow, blue, brown, orange, and red are mostly popular in this area. By changing the metal of the mordant (iron, copper, chromium, aluminum, etc.), the color of the dyed material can also be changed. It may be because of the fact that metal presents in the mordant, reacts with the chromophore group of natural dye, and change its electron stability (Samanta et al. 2017b).

Researchers have reported that the effectivity of natural dye on proteinous wool and jute textiles was found suitable because of the more amorphous zone and the presence of lignin, carboxylic group, etc. The amphoteric nature of wool and the presence of lignin in the jute textile assist them in taking in more amount of natural dye at neutral pH condition. As per the report of the researchers concerning jute textiles, harda and alum are an efficient combination for mordanting, and a mordanted fabric can hold natural dye when it has been dyed at elevated temperature at an alkaline pH condition. As sustainability is one of the major concerns today, even the coloration of synthetic fiber has been attempted by using natural dye extracts. One recent research study reported on the dyeing of polyester and nylon fabric using the extract of the bark of a babool tree. They have reported that a wider range of shades is possible for natural-dyed synthetic textile materials.

20.2.1.2 Value-Added Finishing of Textile by Biomolecule

Different plant biomolecules have been explored for making antimicrobial, UV-protective, fire-retardant textile materials. In addition to this, recently various well-being textiles, vitamin E finishing, and mosquito-repellent textiles have also been made available in the market with an eco-friendly caption.

Antimicrobial Textile

The natural dyes with antimicrobial functionalities are useful in textiles as they not only impart colors but also provide antimicrobial finishing, which can help to increase the life of the fabric and is useful for medicinal garments, sanitary napkins, socks, etc. Cellulosic fabrics like cotton and jute are more prone to be attacked by bacteria, microorganisms, etc. The main source of natural dyes is either plants or microorganisms. Researchers have reported on the use of the bark extract of *Acacia arabica* (babool), *Acacia catechu* (catechu), *Terminalia chebula* (harda) and *Acacia arabica* wild (babool) for making antimicrobial cotton fabric. They have reported that the dye molecule extracted from the mentioned sources is rich in tannin, which may help in the formation of a strong bond with the fiber and thereby assist in the proper fixation of the dye on the fibrous material. Researchers have studied the antibacterial finishing of cotton textile using a neem (*Azadirachta indica*) extract. As per report, researchers have prepared the neem extract from the bark and seed part of the neem tree. The main active ingredient of the neem leaf is limonoid, which is consist of Azadirachtin A, nimbin, and salanin. As per structure, all three components of the neem extract contain polyphenolic group with the presence of anthraquinonoid ring (C=O) in the structure. It also contains tannin group in its structure. Bark extract exhibits antimicrobial activity against both the positive and negative bacteria, respectively, when it has been applied on cotton fabric (Samanta et al. 2015a). One research group has studied the antimicrobial efficacy of sal (*Shorea robusta gaertn F*) bark dye on a mordanted silk fiber. The mordants added on the textile had a significant impact on the color intensity, variation, and fastness properties of the dyed fabric. A maximum change in color has been observed in 3% of the copper-sulfate-mordant-treated samples. They reported that the sal dye also exhibited antibacterial properties, but it has not been studied on dyed fabrics (Samanta et al. 2015b). Likewise, another research group, in their study of the effect of the bark extract of a votiyar tree (*Odina wodier)* on cotton fabric, reported that the said bark extract has good antibacterial and antifungal properties, but the effect has not been studied on the dyed fabric (Chattopadhyay et al. 2016). Apart from it, extracts of various other natural sources like tulasi, pomegranate, turmeric, clove, karanga, henna, cashew shell, cumin, etc. have also been explored in detail by the researchers for making sustainable antimicrobial textile materials. Improving the durability of the antimicrobial treatment is one of the major concerns nowadays, and some of the researchers have used the cross-linking method (by using polycarboxylic acid) and the microencapsulation method (by using guar gum, alginate, etc.). It has been found that the microencapsulation method is more efficient for providing long-lasting effectivity of the finishing after repeated washing. Very recently, researchers are trying to make such kind of textile, which indigenously (does not require any chemical) has antimicrobial effectivity, depending on the structure of the fibrous material. This kind of research concept has been inspired from the various nano-structure surface of water-living animals.

UV-Protective Textile

UV-protective textiles guard living beings from harmful UV rays, which may potentially damage the skin or cause cancer due to overexposure. UV rays have been classified into UVA (315–400 nm), UVB, and UVC (280–315 nm) regions. UVC has a wavelength less than 280 nm and, having a very high intensity, is very much harmful to human beings. It may cause cancer and deadly diseases. Generally, the ozone layer of the atmosphere prevents UVC rays of the sun from entering the earth. With the depletion of some of the areas of the ozone layer, UVC rays are slowly entering the earth. Therefore, people need UV-protective materials like textile to protect their life. The UV protection performance of textiles is measured by the UV protection factor (UPF), with highest protection at values greater than 50 and no protection at values less than 10 (Samanta et al. 2017b). As per scientific report, UPF value of 5–10 may cause skin cancer, 10–20 may tan or occasionally burn the skin, and 20–35 may cause sufficient level of melanin pigment secretion and prevent the skin from burning (Samanta et al. 2017a).

Textile cotton, jute fabric, etc. can be made UV protective by using the extract of different plant products that provide a dark color and contain polyphenolic compounds, tannin, etc. Mongkholrattanasit et al. investigated that dye extracted from the bark of Kurz (*Garcinia dulcis*) not only was useful as a dye but also has UV protection property when applied to silk fabrics. As per their report, the crude application of the extracted dye on the silk fabric gives a light pale yellow color. Mongkholrattanasit R. et.al studied the UV-protective ability of proteinous silk fabric dyed with the bark extract of Magnifera (*Rhizophora apiculata Blume*). The study confirmed that the bark extract provided a UV-protective finishing to the silk fabric. The extent of UV protection also varied from good to excellent, not only with an increase in the concentrations of the dye but also with an increase in the concentration of the mordant. Another research group has investigated the dyeing of cotton fabrics with the extracts of a mangrove plant (*Xylocarpus granatum*), which is commonly used in textile dyeing. The dye is rich in tannin content and is reddish brown in color. The color strength of the dye improves with the application of mordant, which is due to the formation of bridges between the dye, the mordant, and the fabric (Samanta et al. 2015c, d; Alongi et al. 2014a).

Fire-Retardant Textile by Using Biomolecule

Most of the flame retardants used by the textile industries are not eco-friendly and release high ppm of formaldehyde during finishing, which is also released by the finished fabric during storage and use. Therefore, there is a research gap, and researchers are trying to find a kind of chemical that would be easy for textile application, would be less expensive and sustainable, and would have less negative effect on the mechanical properties of the textile. Focusing on this concept, for the last 10 years, different research works have been accomplished. One research group in Italy has reported that DNA extracted from herring sperm and salmon fish consists of phosphate, sugar glucose units of polysaccharide, and some amino acids. The DNA contains phosphorous- and nitrogen-containing groups, and the cotton fabric treated by DNA shows a limiting oxygen index (LOI) of 28, whereas the control fabric shows an LOI value of 18 and burnt easily within 1 min. They have also reported that DNA has more carbonaceous char formation capability and ammonia release property (Alongi et al. 2014b). Efforts were also directed to make cotton fabric flame retardant with other natural products (wastage of paneer industries, chicken slaughter waste, fungus sources, etc.), which are rich in phosphate, disulfide, and protein that can influence the pyrolysis mechanism and reduces flammable gas liberation (Basak and Ali 2018). Apart from this, natural chitosan, maleic acid, phytic acid, tannic acid, vegetable starch, fish bone powder, rice husk silicate, etc. have also been explored by the researchers. Some plant-based materials like banana stem waste, coconut shell extract, pomegranate rind extract, spinach juice, etc. have been applied and reported by the researchers as well (Shukla et al. 2016; Basak and Ali 2019a, b; Basak and Smanta 2018; Kambli et al. 2018).

20.3 Irradiation-Based Technology for Sustainable Textile Processing

As mentioned in the above section, various groups of researchers have engaged in sustainable approaches by using biomolecule-based processing (Basak et al. 2015a, b, c, 2016; Basak and Ali 2016), nanomaterials for textile processing (Seshama et al. 2017; Sharma et al. 2018; Gupta and Basak 2010), irradiation-based processing (Samanta et al. 2014b, 2017a; Chattopadhyay et al. 2016), etc. In this section of the chapter, we have tried to enlist some of the basic irradiation approaches for the modification or functionalization of textile materials.

Various chemical methods such as chlorination, alkali treatment, and synthetic polymer coating have been reported for modifying the fiber surface of textiles. However, these processes are often found to be very harsh and non-eco-friendly, modifying the bulk properties of textile materials, and also generating effluents (Maclaren and Milligan 1981; Jocic et al. 1993). With the increasing environmental concern in recent years and the various government legislation on eco-friendliness and stringent norms on effluent discharge in many countries, alternate environmentally friendly methods with lower pollution load are being explored. One such method is the treatment of textile fabric by irradiation techniques. Different types of irradiation techniques are being utilized as alternatives to the chemical processing of natural and synthetic textiles. Of these, plasma and UV methods are considered to be a clean, cheaper, and multipurpose option. These processes are environmentally friendly, dry, and an energy-saving textile treatment compared to many other traditional methods. Plasma irradiation has been used by researchers for modifying the surface of textiles by physico-chemical reaction. As a result of the physico-chemical changes, the resultant textile material can easily take in dye and other finishing chemicals at lower temperature and in less time. The UV irradiation techniques are normally used to change the nanoscale surface of textiles and also to change the rate of the dyeing of silk, wool, and polyester (Gupta and Basak 2010; Periyasamy et al. 2007a; Gulrajani et al. 2008; Basak and Gupta 2013). Researchers are also using this high-energized VUV irradiation technology for imparting functional finishing and improved serviceability to both natural and synthetic fabrics. Most of the applications reported in the literature are on fabrics made of protein because of their amphoteric nature. It has been reported that irradiation technique can be effectively used to shrink resist wool fabric. The 254-nm UV treatment can modify the wool fabric, lessen its shrinkage, and enhance its dyeing rate and pill-resist properties (Xin et al. 2002). Laser-based surface modification is normally used in aerospace, optoelectronics, automotive industries, the medical sector, etc. However, in some areas, laser rays have also been explored for modifying textile surface and designing textile materials (Morgan et al. 2018; Kan 2008). Very recently, electron beam technology has emerged in the market, which can be used for eco-friendly and clean biodegradable effluent treatment (Deogaonkar et al. 2019; Henniges et al. 2013).

20.3.1 Plasma Irradiation

Plasma is a fourth state of matter and consists of highly ionized, electrically conductive gaseous substances. It emits highly energized rays, which have significant capability to change the physico-chemical properties of the textile surface in a nano scale. However, irradiation treatment cannot alter the major inherent bulk properties of textiles. In general, plasma has been used by various researchers in the material science field for surface modification, grafting, cross-linking, etc. When this highly energized ray falls upon the textile surface, it causes some physico-chemical changes in it. Researchers have reported that cotton fabric can be made hydrophilic and hydrophobic by plasma irradiation in different atmospheres. Plasma irradiation in air and oxygen atmosphere assists to generate carboxylic (–COOH) and hydroxyl (–OH) groups on the fabric surface, and as a result, its hydrophilicity increases. Increased level of hydrophilicity of textile materials help to absorb more amount of chemicals (like dye and finishing chemicals) from the treatment bath in less time.

Indeed, the rate of dyeing or finishing has increased after irradiation. The effect of helium/oxygen plasma treatment on the cotton fabric has been explained by the researchers (Samanta et al. 2010a). As per report, the effect of hydrophilicity is more prominent for the wool fiber because of its amphoteric nature and because its structural composition consists of nanolevel fatty layer. Plasma irradiation helps to break the fatty surface layer of wool and makes it more accessible to the dye or finish chemicals. The irradiation process is sustainable as it minimizes the use of various chlorinated compounds, which has the potential to break the fatty layer of wool. As per report, plasma ray can also be effective on the fabric surface in inert nitrogen atmosphere. This atmosphere helps to generate more positively charged amine groups on the wool surface, which help to pick up more anionic dye from the treatment bath. As a result, dye wastage can be minimized; the temperature required for the treatment is also less compared to the untreated wool textile. On the other hand, plasma can also be applied on the textile surface in helium-flurocarbon gas atmosphere. As per report of the researcher, after treatment, hydrophilic cotton turned into a highly hydrophobic one, and 37 μL was not absorbed by the fabric's surface even after 60 min. In contrast, the control cotton fabric absorbed the same amount of water within 0.05 min (Basak et al. 2015c). After performing various characterizations, the author has confirmed that CF_X molecules deposited on the fabric surface after treatment assist to hold the water droplet on the cotton surface. Apart from this, different phosphorous- and halogen-containing gas plasmas have also been used by the researchers to make fire-resistant cotton fabric. The CF_4 plasma gas was responsible for imparting hydrophobicity and thermal stability of the cotton textile. Plasma irradiation also shows on curing, cross-linking of polymer, grafting, polymerization of monomer on the textile surface, etc. (Samanta et al. 2009, 2010b).

20.3.2 UV Irradiation

UV irradiation lower than 200 nm is also effective for modifying fabric surface with functional groups and physical etching. Mainly it emits highly energized photons that react with atmospheric air and form an ozone gas in the ground state, which again dissociates into oxygen and nascent oxygen (excited state). It is a continuous association and dissociation process. When the excited species falls upon the textile material surface, it generates some free radicals on the surface, and physically the surface of the material is etched. Like plasma, UV rays are also more effective on wool and silk textiles because of their amphoteric nature. Most of the literature reported that UV irradiation helps to break the scales of the wool and also etches the nanolayer thick fatty scales on its surface and reduces the directional frictional effect. As a result, the wool can be made shrink proof without using any chemicals. Another research group has reported that wool can be made easily accessible to anionic acid dye when it has been irradiated by UV rays at inert nitrogen atmosphere. It may be due to the creation of more amount of amine groups on the fabric's surface, which help to catch more acid dye molecules from the dye bath. On the

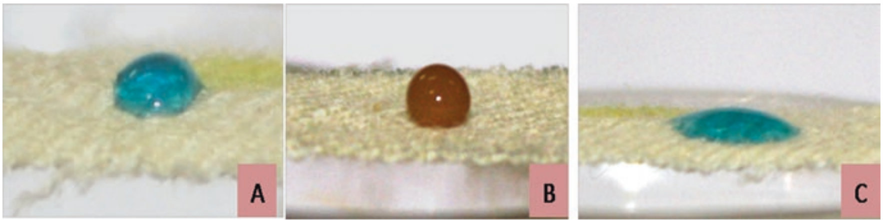

Fig. 20.1 Contact angle measurement of water droplet control wool fabric (**a**), F/C treated nonirradiated side (**b**), and F/C treated 30-min irradiated side (**c**) (Basak et al. 2015d; Periyasamy et al. 2007b)

other hand, UV irradiation in air or oxygen atmosphere creates negatively charged carboxylic and hydroxyl groups on the fabric and helps to catch more basic dye from the dye bath. One of the challenges in this process is that there are major chances of uneven dyeing and ring dyeing after UV treatment. In addition, active species generated on the fabric surface has the possibility of getting aged with time, and so its effectivity could gradually lessen. Researchers have reported the details of the effect of dyeing on UV-irradiated wool fabric in their published papers. The same research group has also made double hydrophilic/hydrophobic wool fabric by using 172-nm UV treatment. According to their report, a multifunctional wool fabric with hydrophobic property on one face and hydrophilicity on the opposite face was prepared by first padding it with fluorocarbon-based composition and then irradiating one side of the fabric with the use of 172-nm UV excimer lamps. The treated samples were then characterized by measurements of contact angle and vertical wicking behavior (Sharma et al. 2018).

It can be seen from Fig. 20.1 that on the irradiated side, the contact angle dropped to 10° after UV treatment. It might be because of irradiation using UV excimer lamp (172 nm); the F/C finish, which has high C–F bond breaking energy, has dissociated and undergone a photo oxidation involving defluorination of the surface (Shukla et al. 2016; Basak and Ali 2019a). Further, some extra polar groups like C=O and –COOH might have also been generated on the 30-min irradiated surface of the treated fabric. On the opposite side, the wool fabric surface shows a lotus effect behavior (Basak et al. 2015d).

UV rays also have a significant effect on the silk fabric surface. Periyasamy et al. (Periyasamy et al. 2007b) have reported surface modification of silk fabric by using an excimer lamp. It has been reported in their manuscript that UV treatment has significantly reduced the wetting time of the irradiated silk fabric compared to the untreated silk fabric. In addition, the rate of wicking of the treated fabric also has been improved significantly. He also elaborates the technical process for developing double hydrophilic/hydrophobic mulberry silk fabric by also using a 172-nm excimer lamp and reported on the detail mechanism behind it in their published paper (Periyasamy et al. 2007b).

20.3.3 Laser Irradiation

Laser emits electromagnetic radiation, depending on optical amplification. Researchers have reported on the effect of laser irradiation on the properties (fabric weight, fiber diameter, abrasion, bending, luster, wetting, etc.) of polyester fabric. They indicated that the laser ray only affects the surface properties of the polyester fabric. However, the performance and comfort properties of the laser-irradiated polyester fabric changed after laser ablation (Kan 2008). Recently, it also has been established the dyeing behavior of CO_2-laser-treated wool fabric. They have reported that laser irradiation approach has a promising effect of reducing energy and water consumption. It has also been reported that laser irradiation improves the dye uptake of the wool textile. However, some tonal variations have been observed on the wool fabric. The same research group has also created various designs on the wool fabric surface through color fading with the help of laser rays (Morgan et al. 2018; Deogaonkar et al. 2019). Chow et al. (2012) have treated cotton fabric with CO_2 laser. They have varied the pixel time and the resolution of the laser for application purposes and have reported that fabric weight and strength decreased with the increase of resolution and pixel time [47, 48]. However, as per report, the treated fabric turned yellowish after treatment. Very recently, another research group has reported on the effect of CO_2 laser treatment on the fabric hand of cotton and cotton/polyester blend fabric. They have explained the effect of laser treatment on the hand properties of the cotton and polyester/cotton blend fabric. In connection to hand properties, they have measured stiffness, smoothness, softness, wrinkle recovery, drapability, etc. and concluded that laser treatment has sufficient capability to change the mentioned hand properties of the fabric.

20.3.4 Electron Beam Irradiation

Electron irradiation is composed of highly energized electrons. Normally, the energy of electrons varies from the KeV to MeV range, depending on the depth of the penetration required. The irradiation dose of the electron beam radiation is generally measured in grays. For the last 5 years, electron beam technology has been used popularly for textile effluent treatment. A researcher has reported on the treatment of textile effluent and nonionic ethoxylated surfactant by electron beam for the removal of color and toxicity (Samanta et al. 2010a). In the same line of work, Deogaonkar et al. (2019) have also reported on the use of electron beam irradiation treatment for the degradation of nonbiodegradable contaminants in textile wastewater. As per this report, electron beam radiation (80 kGy) helps in the biodegradation of effluent, generated from textile desizing, scouring, bleaching, dyeing, and finishing. They have also reported on the biological oxygen demand (BOD) and chemical oxygen demand (COD) of the waste effluent before and after the electron beam treatment (Samanta et al. 2010b).

20.4 Nanotechnology and Other Sustainable Textile Processing

In the past decade, nanotechnology had been widely used by researchers for making value-added textile products. Earlier, different chlorinated products and large molecular weight cationic compounds, like polyhexamethylene biguanide and others, have been widely used by researchers for making antimicrobial textile. However, add-ons, chemical consumption, and toxicity were the biggest challenges. Therefore, nanosilver-based chemicals emerged on the market, and now they are widely used by researchers for making antimicrobial cotton textiles. For wash and wear and durable press finishing of garnets, formaldehyde-based resin, along with sodium hypophosphite, is frequently used by researchers and textile industries. These chemicals have very good cross-linking property and assist in achieving a wrinkle recovery angle of more than 150. However, the treatment affects the strength properties of the fabric, and formaldehyde release is another major concern. Therefore, researchers have tried and developed nano- and polycarboxylic-acid-based, environmentally friendly chemicals for making crease-resistant cotton fabric. As per report, a few textile industries are using poly-carboxylic acids, such as 1,2,3,4-butanetetracarboxylic acid (BTCA), and catalysts, like sodium hypophosphite, for making durable press fabric. However, it is also costly for end users. Self-cleaning technology and lotus effect are more predominant in recent years because of their smart application in textile materials. Superhydrophobic surfaces have also been prepared by using nano titanium dioxide, aluminum oxide, zinc oxide (ZnO) nanoparticles, etc. Recently, nanotechnology has also been explored for making sustainable fire-retardant textile materials. Nano zinc oxide, zinc carbonate, etc. have been explored successfully by researchers for making fire-retardant textiles (Seshama et al. 2017; Sharma et al. 2018). However, as per report, the durability and uniformity of the treatment are the major challenges for its application. Antimony oxide nanoparticle in combination with zinc salt assists to improve the thermal stability of the treated cotton fabric, and the treated fabric shows an LOI value of 24, compared to the LOI value of 18 of the control cotton (Alongi et al. 2014b). Fire-resistant property has been further improved by increasing the add-on percentage on the fabric's surface. Recently, researchers have used ZnO nanoparticles for improving the thermal stability and harmful ultraviolet ray protection functionalities in cotton and blended textiles. The presence of nanodispersed montmorillonite (MMT) clay showed a significant thermal stable property after application on natural polymer substrates (Shukla et al. 2016).

Most of the industries (especially textile industries) generated effluent, which is very much harmful for living beings, as well as for ecosystems. Effluent water has lost its physical, chemical, and biological properties due to mixing with some other contaminants like dyes, heavy metals, pathogens, other inorganic and organic materials, etc. Nanomaterials like metal oxide, metal nanoparticles, zeolite, etc. have already been explored effectively in the field of wastewater purification due to their lower size, high surface area, and size-dependent properties.

20.5 Conclusion

Sustainable development in the textile field is one of the biggest concerns all over the world. Different researches, workshops, and industrial trials are ongoing for the implementation of the different sustainable processes in the textile sector. Among all the technologies developed by researchers, biomolecule-based technologies, water-free processing, and nanoprocessing of textile materials are important. Different technologies like foam finishing, enzymatic treatment, and nano-based processing are commercializing slowly in the industries. However, the cost of treatment, batch-to-batch variation, and repeatability of the treatment are important concerns in most of these areas. In addition, washing and storage durability also need to be taken into consideration. More research and hard work are still required to achieve the sustainability goal in the textile processing sector.

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