Contribution of UV Technology to Sustainable Textile Production and Design

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Abstract The textile and fashion industry is one of the oldest and largest sectors in the World. In the textile industry, it is possible to create both functional and artistic designs by using different materials and different techniques together in harmony. However, it is very important that the applied process types should not harm the environment and living things. Therefore, one of the issues that have come up recently is sustainable textile design. As a result of the developments in today's world, companies invest in technology in order to provide competitive advantage in many sectors and to increase environmental awareness. Textile industry inevitably should re-design their processes in order to reduce the potential environmental damage leading to more sustainable planet for future generations. Therfore, the usage of sustainable, renewable materials and sustainable eco-friendly production methods should be increased in textile industry more and more in order to overcome possible increasing environmental problems arising from the processes of textile sector. In this respect, for instance, ultraviolet (UV) technology offers many alternative innovative usage types not only in the textile industry but also in many other different industrial areas. The usage of UV technology offers so much positive attributes to the textile production and design and also provides sustainable and eco-friendly opportunities for many different areas of the textile industry. The new usage types of UV technology in the textile sector has still been explored today and developed day by day. In this chapter, the information about Ultraviolet (UV) and UV technology, the usage areas of UV technology, the contribution and the production efficiency advantages of UV technology to sustainable textile production and design (such as the use of UV technology in decolorization and purification of textile wastewaters, as pre-treatment and surface modification processes prior to coloration processes, for UV-curing process and for pilling problem prevention etc.) were given in detail.

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S. S. Muthu, M. A. Gardetti (eds.), *Sustainability in the Textile and Apparel Industries*, Sustainable Textiles: Production, Processing, Manufacturing & Chemistry, https://doi.org/10.1007/978-3-030-37929-2_8

Keywords Sustainable · Design · UV · Ultraviolet · Textile · Environment-friendly

Introduction

With the acceleration of industrialization in all sectors of the world, the consumption of the resources and resultant waste production accumulation is unfortunately rapidly and steadily increasing. As in all modern industries, substances left and released to the environment by textile manufacturers are also generally not harmless. For this reason, recently, reducing the amount of damage to the environment and reducing the consumption of the resources for ecological protection, the utilization of environmentally friendly fibers or other materials, reducing the amount of pollution generated, and the development of methods to remove the pollution and pollutants have gained more and more importance. The textile and fashion industry is one of the oldest and largest industries in the world. Today, the textile and fashion industry has been one of the most environmentally damaging sectors to the ecology. In order to solve this ever-increasing problem in the sector, sustainable materials and production methods should be utilized. As is known, textile design fulfills many different purposes in our lives. But proper and more sustainable textile process design is also important for the sustainability of our planet. For this purpose, replacing harmful chemicals with environmentally friendly substances and reducing waste accumulation and resource consumption are of great importance. Again for this purpose, the utilization of sustainable new technologies in the production of textile materials is being investigated. In textile finishing processes, many scientific studies have been carried out on energy-, water-, and time-saving technologies such as plasma, ultrasound, enzyme, ozone, microwave, nanotechnology, and ultraviolet (UV) technology in pretreatment, dyeing, printing, and finishing processes. Moreover, textile industry should re-design their processes in order to reduce the potential environmental damage leading to more sustainable planet.

Developments in the textile industry lead to changes in design and production styles. Changing materials and manufacturing processes continue to influence design from the past to the present. Design is an area where science, technique, and technology combine together in a harmony via creative thinking and aesthetics. If a good design contains both artistic values and is supported by technical equipment and scientific methods, the resulting product shows the ability to combine art with industrial production. It also allows the use of environmentally friendly technologies such as UV technology for clean production in textile. UV rays used in different fields of the textile industry are a kind of electromagnetic wave.

In 1865, the British physicist James Maxwell and the German scientist Hertz discovered electromagnetic waves through his experimental work (Glaze et al. 1987). Radio waves, microwaves, infrared rays, visible light, ultraviolet rays, X-rays, and gamma rays are the types of electromagnetic waves. Ultraviolet is known as a part of the non-ionizing region of the electromagnetic spectrum (United

Nations Environment Programme, the International Labour Organisation, and the World Health Organization 1994). It was first discovered by the German physicist Johann Wilhelm Ritter. Firstly it was expressed as chemical rays by Ritter and then called as ultraviolet (Glaze et al. 1987). The word meaning is derived from Latin and means that it is "beyond violet" (Ansiklopedi 2016). The position of ultraviolet rays in the electromagnetic spectrum is characterized by a wavelength (United Nations Environment Programme, the International Labour Organisation, and the World Health Organization 1994; Bintsis et al. 2000). Wavelengths vary between 10 and 400 nm (nanometer). According to the energy emitted by ultraviolet, they are classified as UV-A, UV-B, UV-C, and vacuum UV (Perincek et al. 2007; Karahan et al. 2007; Saravanan 2007; Mutlu et al. 2003; Perkins 2000; Reinert et al. 1997; Özkütük 2007).

Although most of the UV rays are held by gases in the atmosphere, some of them reach to the earth. In case of excessive exposure to UV rays, it is known to result in human health damage. The usage areas and purposes of UV are changing with the developing technology. It is used in many industries with the advantage of being an environmentally friendly technology. UV technology, which is widely used in disinfection of liquids (Özkütük 2007; Keyser et al. 2008; Koutchma 2009; Pala and Toklucu 2010; Teknolojisi 2019; Fredericks et al. 2011), is used in the pasteurization process of liquid foods in the food industry (Keyser et al. 2008; Koutchma 2009; Pala and Toklucu 2010). It is also used for disinfection of hemodialysis systems in medicine (Sezdi and Benli 2016; Şimşek and Sultan 2013) and disinfection process of textile wastewater in textile sector (Colonna et al. 1999; Georgiou et al. 2002; Konstantinou and Albanis 2004; Robinson et al. 2001). Especially in textile enterprises, massive amount of water is generally used during the finishing processes leading to high wastewater load. The use of environmentally friendly new methods in the treatment of textile wastewater provides the recovery of purified water (Bahtiyari 2009; Kitiş et al. 2009). The logic of the disinfection process with UV technology is almost the same for every sector. UV rays impair the DNA structure of harmful microorganisms formed in the liquids. It breaks the chains between two spirals in the DNA and causes the death of microorganisms (Pest Products 2011; Aydın 2009). In the purification of industrial wastewater, chemical degradation processes are provided with UV/O_3 or UV/H_2O_2. In addition, TiO_2/UV is widely used in the photocatalytic oxidation process, which enables the treatment of wastewater (Glaze et al. 1987; Colonna et al. 1999; Robinson et al. 2001; Güneş and Talınlı 2007; Zhang et al. 1998; Arslan and Balcioğlu 1999). Since no chemicals are used during these processes, there is no change in the chemical structure of liquids (Fredericks et al. 2011; Aydın 2009). Many studies in this area are included in the literature (Glaze et al. 1987; Colonna et al. 1999; Robinson et al. 2001; Güneş and Talınlı 2007; Zhang et al. 1998; Arslan and Balcioğlu 1999). Besides, UV technology is used also for anti-pilling process of wool and cotton fabrics (Perincek et al. 2007; El-Sayed and El-Khatib 2005). Although chemical processes such as chlorination can be widely used for this purpose, the formation of adsorbable organohalogens (AOX) during the process has led to the development of alternative methods such as UV technology (El-Sayed and El-Khatib 2005).

In 1998, Siroflash anti-pilling process was introduced by Millington. The Siroflash anti-pilling process for knitted fabrics is a process involving exposure to short-wavelength ultraviolet radiation (UV-C) of the fabric or garment surface. A light wet oxidation process is applied to the fabric exposed to ultraviolet radiation using, for instance, hydrogen peroxide or permonosulfuric acid salts (El-Sayed and El-Khatib 2005; Millington 1998a). Thus, the weak fibers which cause pilling on the surface of the textile materials are removed from the fabric surface, and the materials are prepared for the next processing step (such as dye and printing) (Perincek et al. 2007).Textile products may need to be modified before dyeing to increase dyestuff intake. Some studies in the literature suggest that UV technology provides significant advantages in dyeing (Millington 2000; Iqbal et al. 2008). By using ecologically acceptable UV-assisted treatments, modification of textile materials, in particular wool, is provided (El-Sayed and El-Khatib 2005). It was reported that more dyestuff intake and good fixation at low temperatures can be provided with the modification of the fiber surfaces. As an outcome of oxidation of surface fibers by UV radiation, treated textile materials exhibited higher color strength (Millington 2000; Iqbal et al. 2008). The influence of UV radiation on natural and synthetic dyes also gives quite important results (Bhatti et al. 2011). UV/O_3 is generally used as a surface modification process. Short UV radiation combined with ozone disintegrates covalent bonds in many organic materials. For example, this process may result in photooxidation of poly(trimethylene terephthalate) (PTT) film. PET and PTT fabrics treated with UV/O_3 radiation are dyed with black disperse dyes, and UV radiation-treated fabrics displayed deep dyeing effect (Karahan et al. 2007; Jang and Jeong 2006). In addition, UV technology can also be used for curing processes. UV curing has found different application areas in various industrial sectors. It offers advantages such as providing ultrafast polymerization of solvent-free formulations. UV curing that is used in textile printing process is used to produce prepress printing plates. In addition, the use of UV-curable inks during printing provides fast drying. This situation significantly increases the processing speed and reduces energy consumption (Decker 2002, 1996). Today, the ability of the countries to achieve superiority in the international market depends on technological innovations. For this purpose, advantages of new technologies such as UV technology in textile field are very valuable (Perincek et al. 2007). The usage of UV technology offers so much positive attributes to the textile production and design and also provides sustainable and eco-friendly opportunities for many different areas of the textile industry. Textile industry should re-design their processes in order to reduce the potential environmental damage leading to more sustainable planet. Moreover, increasing competition between the companies enhances their interest in the utilization of novel technologies such as ultraviolet technology in their textile processes. Thus, while the quality of their products and services may increase, their potential hazardous damage to the environment could be diminished and/or eliminated.

It is known that UV technology can be used for various purposes in different areas of industry. In this chapter, the information about ultraviolet (UV) and UV technology, the usage areas of UV technology, and the contribution and the production efficiency advantages of UV technology to sustainable textile production and design (the use of UV technology in decolorization and purification of textile wastewaters, as pretreatment and surface modification processes prior to coloration processes, for UV curing process and for pilling problem prevention, etc.) were given in detail.

In this chapter, the contribution of UV technology to sustainable textile production and design is reviewed. Firstly, brief information about electromagnetic field and electromagnetic spectrum, ultraviolet, ultraviolet rays, and history of ultraviolet is given. Then, the different contributions of ultraviolet technology to sustainable process design in the textile sector were introduced. Finally, different application areas of ultraviolet technology in the textile production such as decolorization and purification of textile wastewaters, pretreatment and surface modification process prior to coloration processes, curing, and the pilling problem prevention are examined in detail.

Electromagnetic Waves and Electromagnetic Spectrum

Electromagnetic waves are a kind of vibration that can spread very quickly in space. The invention of electromagnetic waves and basic works were carried out by James Clerk Maxwell and Heinrich Hertz. Electromagnetic waves are classified according to the wavelength. Physical events we experience on a daily basis show us the presence of an electromagnetic wave, for example, sunrise, cooking your meal with microwave, etc. The types of electromagnetic waves are radio waves, microwaves, infrared rays, visible light, ultraviolet rays, X-rays and gamma rays. These are separated from each other by only wavelength (Sengupta and Sarkar 2003). Electromagnetic waves spread over a very wide area according to wavelength and energy. Electromagnetic spectrum is obtained by classifying electromagnetic waves according to frequency and wavelength. The light waves we can see are also part of the electromagnetic spectrum. Electromagnetic waves are classified from the longest wavelength to the shortest wavelength in the electromagnetic spectrum. The smallest frequency or the largest wavelength of electromagnetic waves is radio waves. The highest frequency or the smallest wavelength of electromagnetic waves is gamma rays. The frequency increases, and the wavelength decreases from left to right in the electromagnetic spectrum (Aksoy 2019).

Ultraviolet

Ultraviolet is called “beyond violet,” and the color of the uppermost frequencies of seeable light is violet. Ultraviolet possesses a higher frequency than violet light, and ultraviolet rays are electromagnetic radiation of between visible rays and X-rays. Ultraviolet rays have longer wavelengths than X-rays and shorter wavelengths than visible rays (Ansiklopedi 2016; Attwood and Sakdinawat 2017). They are not visible to the human eye because of the shortness of their wavelength (Karahan et al. 2007; Kaizenisg 2012; Diffey 2002). Ultraviolet (UV) radiation is a form of light energy from the sun (Mutlu et al. 2003). They have wavelengths between 10 and 400 nanometers (Ansiklopedi 2016; Özkütük 2007). It consists of frequencies greater than 789 THz. A single light cluster has energy of 3.26 eV (Diffey 2002). Ultraviolet rays, which are harmful to the skin, cause sunburn and skin cancer (Ansiklopedi 2016). Ultraviolet also provides the formation of vitamin D which provides strengthening of the bones of all living creatures living on land. The UV spectrum thus possesses effects both beneficial and harmful to human health (Ansiklopedi 2016). Scientists had separated the ultraviolet part of the spectrum into three as UV, far UV, and far-off UV. This distinction made by scientists is based on the energy of UV radiation. Wavelength of UV light is expressed by energy. The sun emits radiation from all wavelengths in the electromagnetic spectrum and is known as the greatest source of ultraviolet radiation (Kaizenisg 2012; Diffey 2002). About 9% of the energy emitted from the sun is ultraviolet radiation. Fourteen percent of the ultraviolet radiation emitted from the sun belongs to the wavelength region smaller than 3000 Angstrom (A°) (Kaizenisg 2012). Ultraviolet rays form a very low fraction in the solar spectrum but affect all living organisms and their metabolism (Saravanan 2007). More than half of the ultraviolet (UV) rays from the sun are kept in the atmosphere (Kaizenisg 2012; Diffey 2002). Some ultraviolet waves pass the earth's atmosphere, but are kept by some gases such as the ozone layer (Perincek et al. 2007; Karahan et al. 2007).

The electromagnetic spectrum of ultraviolet radiation (UVR), which can be described the most broadly as 10–400 nanometers, could be subdivided into a number of ranges advised by the ISO standard ISO-21348 (Ansiklopedi 2016; Özkütük 2007). Ultraviolet rays are grouped among themselves according to different wavelengths. Physicists make this classification as close UV (320–380 nm), medium UV (200–320 nm), and vacuum UV (10–200 nm) (Perincek et al. 2007; Karahan et al. 2007; Saravanan 2007). The term UV-A represents a region of 320–400 nm, while the term UV-B represents a region of 290–320 nm, and the UV-C region represents the region below 290 m. The order of impact has been determined as UV-C > UV-B > UV-A (Saravanan 2007; Mutlu et al. 2003; Perkins 2000; Reinert et al. 1997; Özkütük 2007). An example of ultraviolet rays is shown in Fig. 1.

Long-Wave UV (UV-A)

Wavelengths of UV-A rays are between 320 and 400 nm. At the same time, UV-A rays have the highest wavelength and least energy compared to other UV rays. UV-A rays emitted from the sun are held by the atmosphere. Most UV-A rays are not affected by ozone and pass directly through the ozone layer. In other words, 95–98% of UV-A rays reach to the earth (Ansiklopedi 2016; Perincek et al. 2007; Karahan et al. 2007; Mutlu et al. 2003; Madronich et al. 1998). Excessive exposure to UV-A radiation from the sun causes skin problems and diseases. In particular,

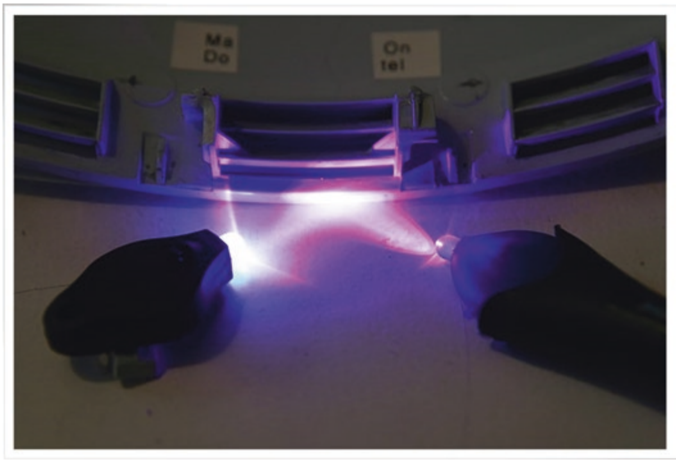

Fig. 1 Ultraviolet rays (Wikimedia Commons 2019)

it reaches and spreads to the deep layers of the skin (dermis). This type of UV is widely used in lighting systems in industry (Karahan et al. 2007).

Middle-Wave UV (UV-B)

The wavelengths of UV-B rays are between 280 and 320 nm. The wavelengths and energy of the UV-B rays are in the middle of the UV band. It is stronger than UV-A rays with longer wavelength rays. Seventy to eighty percent of the UV-B rays are kept by ozone, water vapor, oxygen, and carbon dioxide. UV-A rays form the largest part of UV rays reaching the earth through the atmosphere, and a small portion of it also forms UV-B rays. Two to five percent of the UV-B rays from the sun reach the earth, and UV-B radiation is potentially very harmful (Perincek et al. 2007; Karahan et al. 2007; Mutlu et al. 2003; Madronich et al. 1998). The UV-B rays, which significantly affect human health, reach the upper layer of the skin and cause skin cancers. In addition, it also causes health problems such as temporary blindness and cataract. In industry, these rays are generally known to be used in lighting systems (Perincek et al. 2007; Karahan et al. 2007).

Short-Wave UV (UV-C)

UV-C rays are known as rays that have the shortest wavelengths and the highest energy at the ultraviolet band. The wavelength of UV-C rays varies between 200 and 280 nm (Perincek et al. 2007; Mutlu et al. 2003). Some sources evaluate vacuum UV as UV-C. Therefore, according to these sources, the wavelengths of UV-C rays indicate 100–280 nm (Karahan et al. 2007; Madronich et al. 1998). UV-C rays emitted from the sun are filtered by the ozone layer or absorbed by other gases in the atmosphere (Perincek et al. 2007; Mutlu et al. 2003). It causes serious health problems when exposed to UV-C rays. UV-C rays can be produced by using electrical energy as a result of electronic industrial processes. UV-C rays, which have lost their energy when they come into contact with any surface, are recently used in surface modifications (Perincek et al. 2007; Karahan et al. 2007).

Vacuum UV

Vacuum UV wavelength is between 100 and 200 nm (Diffey 2002). Vacuum UV, its wavelengths shorter than 200 nm, are strongly absorbed by molecular oxygen in the air, although the longer wavelengths of about 150–200 nm could propagate through nitrogen (Ansiklopedi 2016; McPherson et al. 1987). Vacuum UV with very short wavelength produces ozone by separating the oxygen in the air. Ozone (O_3) can only be measured in vacuum. Vacuum UV radiation is used in surface cleaning/purification, photooxidation, surface activation, and ozone production (Diffey 2002).

History of Ultraviolet

The existence of ultraviolet rays was first discovered by German physicist Johann Wilhelm Ritter in 1801. Ritter has studied the effect of X-rays on chemical substances and observed that invisible rays just beyond the violet end of the visible spectrum darkened silver chloride-soaked paper more quickly than violet light itself. In other words, he noticed that there was an energy output in the dark band beyond the violet light (Ansiklopedi 2016). He called these rays as oxidizing rays to accentuate its chemical reactivity. Thus it is easier to distinguish them from the heat rays. The term of chemical rays which is the simpler expression was adopted shortly afterwards. During the nineteenth century, there were people who thought that ultraviolet rays, known as chemical rays, were a completely different kind of radiation from light. In time, the terms chemical rays and heat rays were called ultraviolet and infrared rays, respectively. In 1878, it was observed that short-wavelength light killed bacteria. Thus, sterilizing effect was first discovered. In 1903, it was learned that the most effective wavelength was around 250 nm, and in the 1960s, ultraviolet radiation has been found to be effective on DNA (Glaze et al. 1987). In 1893, the German physicist Victor Schumann discovered that ultraviolet radiation at wavelengths below 200 nm was absorbed by the air. For this reason, ultraviolet radiation at wavelengths below 200 nm is called "vacuum ultraviolet" by Victor Schumann.

Table 1 Usage areas and its related wavelengths of UV technology in different sectors (Ansiklopedi 2016; Özkütük 2007; Keyser et al. 2008; Koutchma 2009; Pala and Toklucu 2010; Teknolojisi 2019; Fredericks et al. 2011; Pest Products 2011; Decker 2002, 1996; Gaillard and Gilbert 1997; Feyler 2004; Apollonio et al. 2006; Smith 2004; Mager et al. 1999; Elman and Lebzelter 2004)

Wavelength (nm)	Application area	Reference
13.5	Excessive ultraviolet lithography	Ansiklopedi (2016)
30–200	Photoionization, ultraviolet photoelectron spectroscopy	Ansiklopedi (2016)
200–400	Judicial test, medicament detection	Ansiklopedi (2016), Gaillard and Gilbert (1997)
200–270	Disinfection of liquids Disinfection of fluid food products (antimicrobial effect)	Ansiklopedi (2016), Pest Products (2011)
230–365	UV-ID, sticker chasing, barcodes	Ansiklopedi (2016), Feyler (2004)
230–400	Optical sensors, several instrumentation	Ansiklopedi (2016)
240–280	Cleansing of surfaces and water (DNA absorption has a peak at 260 nm)	Ansiklopedi (2016), Özkütük (2007), Keyser et al. (2008), Koutchma (2009), Pala and Toklucu (2010), Teknolojisi (2019), Fredericks et al. (2011)
254	Protein analysis, DNA sequencing	Ansiklopedi (2016); Apollonio et al. (2006)
270–360	Protein analysis, DNA sequencing	Ansiklopedi (2016), Gaillard and Gilbert (1997), Smith (2004)
280–400	Medical imaging of cells	Ansiklopedi (2016)
300–320	Light therapy in medicine	Ansiklopedi (2016), Mager et al. (1999)
300–365	Curing and printer inks	Ansiklopedi (2016), Decker (2002), Decker (1996)
407–420	Light therapy in treatment	Ansiklopedi (2016), Elman and Lebzelter (2004)

Usage Areas of Ultraviolet Technology

Ultraviolet technology is now being used in almost all sectors. There is a usage area spreading in food, cosmetic, medical, electrical, and textile sectors. It is effective in damaging the living cells and killing bacteria in sectors such as medicine and food. Therefore, it is a type of radiation used in phototherapy or water sterilization. Moreover, UV technology can also be used for forensic analysis and drug detection (Ansiklopedi 2016; Gaillard and Gilbert 1997). Ultraviolet rays make some chemical reactions easier (Ansiklopedi 2016; Karahan et al. 2007). Therefore, the use of aqueous foods in pasteurization is also increasing (Keyser et al. 2008; Koutchma

2009; Pala and Toklucu 2010). In addition, the use of UV technology in disinfection of wastewater also prevents the environmental pollution caused by textile wastewater (Georgiou et al. 2002; Konstantinou and Albanis 2004; Robinson et al. 2001). It is known that in the textile sector, UV technology can be used not only to disinfect wastewater but also to increase dye intake via its application prior to coloration processes such as dyeing and printing. It can also be used as an alternative to the chlorination process in the production of black and navy blue fabrics especially used in Japan as an official costume (Perincek et al. 2007). It is also used for UV curing process of polymers and printing inks (Decker 2002, 1996). It also provides removal of weak fibers that cause the formation of pilling on the surface of woolen knitted materials. Moreover, UV technology is also used for surface modifications of textile materials (Perincek et al. 2007; Karahan et al. 2007). The different application areas of UV technology in different sectors and its related wavelengths are shown in Table 1 (Ansiklopedi 2016).

Uses of Ultraviolet Technology in Textile Sector

When it comes to the relation of UV and textile, one may think, at first thought, that textile materials (apparel, garment, clothing, curtains, etc.) are generally used to protect us against the harmful effects of UV rays which were generally emitted from the sun (Saravanan 2007). However, the relation between the textile materials and UV rays of the sun is not that limited. In the recent years, physicochemical methods performed with UV radiation are being more preferred instead of chemical methods in the surface modifications of textile materials. In UV surface treatments, generally photoinitiators are used, and thus the yield obtained is increased (Ansiklopedi 2016; Karahan et al. 2007). The use of UV radiation to change the surface properties of fabric has a commercial importance, and it is considered as an alternative to conventional methods. While the fabric surface is modified by UV radiation, the main properties of the textile materials do not change. During this process, high-density surface fibers serve as a layer to prevent UV rays from penetrating into the interior. Thus, the main fibers providing the fabric strength are protected. In order for this process to be carried out correctly, the surface fibers must be directly absorbed by UV rays, or when exposed to UV rays, suitable photoinitiators should be used to produce large amounts of reactive free radicals. The photoinitiators used in textile applications are odorless, non-toxic, and cheap and can be easily removed by washing. For this reason, aromatic photoinitiators are generally used in most UV applications (Perincek et al. 2007).

UV treatment also benefits the coloration process (such as dyeing and printing) of textile products. Owing to the modification of the fabric surface with UV rays, more dyestuffs can be fixed more rapidly leading to darker shades and colors. It also increases the wettability of hydrophobic fibers in the printing process and prevents the pilling problem formation especially for the knitted fabrics (Perincek et al. 2007).

Ozone is formed when UV rays react with air oxygen. The UV rays then react with the ozone formed, resulting in the formation of monoatomic oxygen, which is highly reactive and suitable for the oxidation of the fibers. In addition, UV photons ensure that the bonds on the fiber surface are broken and change the structure, so as to react with ozone and monoatomic oxygen. This double effect is important for rapid oxidation of the fiber surface and that the fiber exhibits the desired interactions with the matrix in the composite materials (Karahan et al. 2007; Qin et al. 2015). Seventekin et al. injected acrylic acid on polyester using a high-pressure UV lamp. They used benzophenone as the initiator and made the polyester fibers hydrophilic. And then the researchers measured the resistance to washing of the dirt-repellent properties of the polyester fibers which became hydrophilic (Karahan et al. 2007; Kurbus et al. 2003).

UV Technology Usage in Sustainable Process Design

Design in textile means the combination of color, texture, and lines with creativity (Gürcüm 2016). However, the process for the formation of a product is also included in the design. Process design includes the works that determine how the product or parts of the product will be produced in which kind of production process, through which hardware tools. Design has been interpreted with various definitions by designers and researchers as "decision-making in uncertainty," "finding the right physical components of a physical structure," "imaginary leap from the realities of the present to the probabilities of future," "problem-solving process," "cognitive process," "reflection in action," and "knowledge-based activity" (Gürcüm 2016). The design is described by Elizabeth Adams Hurwitz succinctly as the search for what is necessary (Ansiklopedi 2019).

When all the comments made for the design are evaluated, the design can be seen as a process for solving a specific problem (Gürcüm 2016). The goal of this process is to identify the problem and to find sustainable and creative solutions to meet the needs. One of the most important elements of design is functionality. Product functionality is provided by process designs and current production technologies. It is very important that these processes are environmentally friendly, sustainable, and clean energy (Gürcüm 2016). Sustainable process design looks for the answer to the question of how to produce the product in a sustainable way. Today, a new aesthetic understanding is formed with process designs that will make a difference in textile materials created with innovative technologies (Gürcüm 2016; Erbiyikli 2012). With the interpretation of traditional or known applications with creative and innovative developments, new opportunities for unusual materials are developed, and new concepts are developed, and new insights are formed (Erbiyikli 2012).

For instance, Semiha Eren's work in 2019 is an example of the use of UV technology in sustainable process design (Eren 2019). In this study, photocatalytic clearing process of disperse dyed polyester fabric with UV light was emphasized. Dyed polyester fabrics treated with different concentrations of hydrogen peroxide were exposed to 254 nm of UV radiation. The fabrics were treated with UV radiation for 5 min, 10 min, 20 min, and 30 min, respectively. The photocatalytic clearing of disperse dyed polyesters was compared with conventional reduction clearing. It was concluded that the use of UV in the photocatalytic clearing process of dyed polyester fabrics causes less damage to the environment than the traditional method. They also obtained comparable washing fastness results. In addition, the use of UV radiation in photocatalytic clearing is stated to be a different, novel, and sustainable process design (Eren 2019).

In the below sections, other than the use of UV technology for the clearing of dyed polyester, other different contributions of ultraviolet technology to sustainable process design in the textile sector (decolorization and purification of textile wastewaters, pretreatment and surface modification process prior to coloration processes, curing, and the pilling problem prevention) were examined in more detail.

The Use of UV Technology in the Decolorization and Purification of Textile Wastewaters

UV treatment systems provide an environmentally friendly and highly efficient disinfection for a sustainable environment and healthy living (Teknolojisi 2019). Textile industries manufacture large amounts of wastewater because of their high consumption of water primarily in the dyeing and finishing operations (Georgiou et al. 2002). Wastewater containing a great variety of organic contaminants in a wide range of concentrations may cause disturbance to the ecological system of the receiving water (Colonna et al. 1999; Georgiou et al. 2002; Konstantinou and Albanis 2004; Robinson et al. 2001; Kurbus et al. 2003). The release of this wastewater into the environment may lead to serious environmental pollution. The chemical reactions in the wastewater phase (such as oxidation and hydrolysis) result in the formation of dangerous byproducts (Konstantinou and Albanis 2004; Kurbus et al. 2003). This poses a danger to the health of living creatures in the environment (Konstantinou and Albanis 2004). Generally, biological purification systems and methods are utilized in the treatment of such industrial wastewater (Colonna et al. 1999; Güneş and Talınlı 2007). But, because of the large degree of aromatics present in dye molecules and the stability of modern dyes, conventional biological treatment methods are insufficient for decolorization and degradation (Konstantinou and Albanis 2004; Robinson et al. 2001; Arslan and Balcioğlu 1999). It is now possible to oxidize and break down wastewaters by using oxidation technologies. Many oxidation processes are used for this aim. These include chemical disintegration processes (UV/O_3, UV/H_2O_2), photocatalysts (TiO_2/UV, photophone reagents), and chemical oxidation processes (O_3, O_3/H_2O_2, Fenton) (Glaze et al. 1987; Colonna et al. 1999; Robinson et al. 2001; Güneş and Talınlı 2007; Zhang et al. 1998; Arslan and Balcioğlu 1999; Kurbus et al. 2003). Advanced oxidation processes such as TiO_2/UV have been studied in detail in the literature (Arslan and Balcioğlu 1999). In the photocatalytic oxidation, TiO_2 should be irradiated and excited in a near-UV energy to induce charge separation. It is hard to conclude whether the photocatalytic oxidation is superior to the photosensitizing oxidation mechanism; however the photosensitizing mechanism will aid to improve the overall efficacy and make the photobleaching of dyes utilizing solar light more feasible (Arslan and Balcioğlu 1999; Epling and Lin 2002). Effective destruction of azo dyes belonging to different chemical groups seems possible by TiO_2/UV (Arslan and Balcioğlu 1999).

Although the combination of ozone and UV technology is widely used for the treatment of textile wastewater, it can take on a task that catalyzes the formation of ultraviolet-hydrogen peroxide or chlorinated compounds (Perincek et al. 2007). UV wavelengths of 200–280 nm result in disassociation of H_2O_2 with mercury lamps emitting at 254 nm which is the most commonly utilized one. It is known that UV/H_2O_2 systems generate hydroxyl radicals (OH) that are highly powerful oxidizing species. Hydroxyl radicals could oxidize organic compounds (RH) fabricating organic radicals (R) that are highly reactive and could be further oxidized (Glaze et al. 1987; Georgiou et al. 2002; Kurbus et al. 2003). Thus, the dyestuffs in textile wastewater are disintegrated, and many organic impurities are destroyed (Perincek et al. 2007; Kurbus et al. 2003).

Many research studies have been done on the purification of textile wastewater with UV technology and are still being carried out. Some studies in the literature have tested several azo-reactive dyes and cotton textile wastewater under UV irradiation in the existence of hydrogen peroxide (H_2O_2). Researchers used a 120 W UV lamp, protected by a quartz tube, emitting at 253.7 nm as a radiation source. Complete destruction of the color of the dye solutions was achieved in the first 20–30 min of irradiation. UV/H_2O_2 proved that it was capable of the complete degradation and mineralization of the azo-reactive dyes (Georgiou et al. 2002). UV radiation in the existence of hydrogen peroxide results in complete decolorization and mineralization of sulfonated azo and anthraquinone dyes in a relatively short period. But, anthraquinone dyes generally seem to be a little more resistant to the treatment than azo dyes. UV/H_2O_2 treatment seems a very encouraging technique for reduction of organic pollutants in the industrial wastewaters. UV/H_2O_2 treatment seems to be a quite successful method for reduction of organic pollutants in the industrial wastewaters (Colonna et al. 1999; Robinson et al. 2001). Semiconductor photocatalysis usually results in partial or complete mineralization of organic pollutants (Chakrabarti and Dutta 2004). In the process of UV radiation treatment, semiconductors catalyze redox reactions with air and water (Chakrabarti and Dutta 2004).

After the biological treatment of wastewater, UV disinfection is carried out before being given to the natural environment. These waters are used for recycling or irrigation purposes (Aydın 2009). The greatest advantage of UV technology is its environmentally friendly nature and its chemical disinfection procuration. It does not change the chemical properties of water (such as conductivity and pH) since the chemical is not given into the water. When chlorine or chlorinated disinfectants are used in the water, carcinogenic compounds called THM (trihalomethanes) can be formed. Carcinogenic byproducts are not formed in the disinfection processing with UV technology. In addition to all these positive attributes, disinfection with UV technology is also very fast (Aydın 2009).

The Use of UV Technology as a Pretreatment and Surface Modification Process Prior to Coloration Processes

UV technology can be utilized for bleaching and surface modification processes prior to coloration processes such as dyeing and printing. In textile finishing, bleaching of the product is a quite important process since it affects the brightness and color shade of the dyeing process. In particular, the removal of the natural yellowish color of cotton and some impurities is possible by bleaching. The most common bleaching agent utilized in textile is hydrogen peroxide (H_2O_2) (Eren 2018). However, in the bleaching process with hydrogen peroxide, caustic soda is required for activation of hydrogen peroxide, and moreover stabilizer is needed to prevent catalytic damage. What is more, wetting agents for better penetration and high temperature are also required. Therefore, methods with less environmental impacts for bleaching of cotton continue to be explored. In a study by Eren S. (2018), UV technology is used as a cleaner bleaching method (Eren 2018). The hydrogen peroxide treatment carried out under UV radiation is considered an advanced oxidation treatment. The main oxidizing agent in the H_2O_2/UV advanced oxidation process is the hydroxyl radical (-OH) which is created by the application of UV radiation on H_2O_2. It was reported that the H_2O_2/UV advanced oxidation process, which also can be used in bleaching soybean fabrics, is also very suitable for cotton bleaching (Eren 2018). In here, Eren S. examined the photocatalytic bleaching of cotton by H_2O_2/UV. She used 254 nm UV light and a specially designed 470 Watt cabinet with 18 UV lamps in this study. Whiteness of cotton samples bleached by H_2O_2/UV treatment with the whiteness of traditionally bleached (pad-steam method) cotton fabric samples was compared. It was concluded that the best whiteness levels were obtained for 40 and 60 min treatment times with H_2O_2/UV treatment (Eren 2018). Thus, the bleaching process carried out with the help of UV technology proves that this technology type can be an alternative to traditional methods both by being environment friendly and providing sufficient whiteness (Eren 2018).

Another application type of the UV technology in the textile industry is a pre-modification process prior to the coloration process of the textile material. In fact, color is the most important element of design and ultimate purchase decision. Precursor radiation treatment on fabrics and garments is a value added process for coloration process. In here, the modification of the fiber surface allows more dye uptake and higher fixation rates at low application temperatures leading to increased wettability (Bhatti et al. 2011; Kim et al. 2005). This also facilitates the applicability of different pattern designs.

The most important advantages of UV technology over other methods applied are energy saving, low-temperature process applicability, low environmental effect, simple, economical, and high treatment speed (Bhatti et al. 2011). Nevertheless, the number of radiation curing applications for nonwoven fabric bonding, fabric coating, and pigment printing is low in the textile industry (Ferrero and Periolatto 2011). It was stated that the influence of UV radiation on natural and synthetic dye results in important outcomes (Bhatti et al. 2011). Some studies in the literature prove that UV irradiation adds value to coloration and also enhances the dye uptake capability of the cotton fabrics through oxidation of the surface fibers of cellulose and besides resulted in even shade with higher color strength (Millington 2000; Iqbal et al. 2008).

It was stated that the UV irradiation of fabric is also another factor that influences the color strength of the fabric (Millington 2000; Iqbal et al. 2008; Bhatti et al. 2011). The effect of UV irradiation on color strength was tested using appropriate dyes and fabrics.

According to the test results, the UV-irradiated fabric displayed better color strength than the UV-non-irradiated fabric. It has been observed that the fabric exposed to UV radiation for 120 min exhibited maximum color strength value (Bhatti et al. 2011). The reason of this may be the result of the cellulose oxidation due to UV light exposure. Oxidation of cellulose on UV radiation expressively upsurges the dye intake into the substrate (Micheal and El-Zaher 2005).

The research carried out by Michael and EL-Zaher in 2005 proved that the UV treatment of cellulose fiber created spaces between the fibers which take more dye, and as an outcome, the interaction between dye and cellulose fabric becomes more substantial. It was reported that the dye particles rush fast onto the fabric, and as an outcome, darker shades were obtained (Bhatti et al. 2011; Micheal and El-Zaher 2005; Adeel et al. 2012). In the studies conducted by Millington, it has been observed that as a result of the UV processes called photo-modification, better hydrophilicity can be imparted to the textile material. Also the color productivity obtained as a result of dyeing and printing processes is increased, and even the coloration takes place in a shorter time and at a lower application temperature. They have reported that the tendency of pilling was also reduced in cotton and wool knitted fabrics. If the number of cross-links due to the effect of UV rays is high, it loses its fabric durability and acquires a rigid structure, which has a negative effect on the comfort of the garment. In the case of excessive number of cross-links due to UV rays' effect, it loses its fabric casting and acquires a rigid structure. For this reason, it has a negative effect on the comfort of the garment (Karahan et al. 2007). As with all high-energy sources, extreme UV radiation results in photo-degradation and degradation of the physical properties of the product (Karahan et al. 2007; Waddell et al. 1992). Previous study by K. R. Millington suggested that photo-modification of the surface fiber could lead to more dye uptake to produce deeper shades (Millington 1998b). It is concluded that UV radiation provides faster fixation of dyes and enhances the wettability of hydrophobic fibers to improve depth and shade in printing (Millington 1998b).

Jang and Jeong studied the surface modification of PET and PTT fibers using UV/O_3 combination. At the end of the treatment, the surface which gains anionic character has increased dyeability due to electrostatic interaction with cationic dyes (Karahan et al. 2007; Jang and Jeong 2006). Lately, UV/O_3 treatment has become more and more popular and practical since its process type has several advantages in comparison with the other well-known surface modification methods. The UV light, which is less than 340 nm, breaks the covalent bonds of C-C, C-O, and C-H in the structure of many organic materials together with the ozone, and this causes photooxidation. Molecular oxygen absorbs UV light emission and manufactures ozone with a reaction of the molecular oxygen and ground-state oxygen, and ozone absorption of 253.7 nm light leads to singlet atomic oxygen manufacture. It was stated that UV/O_3 radiation can be used to obtain deep tones when PET and PTT fabrics are dyed with black disperse dyes (Jang and Jeong 2006).

In another study, UV/ozone irradiation, as a surface modification process, and fluorocarbon finishing combinations were applied to polyester fabrics (Rahmatinejad et al. 2016). In here, the enhancement in polyester substrates hydrophobicity was done by surface modification via chemical pretreatment, UV-ozone irradiation, and fluorocarbon finishing combinations. The outcomes of the study exhibited the usefulness of UV-ozone treatment for creating proper surface roughness to improve the hydrophobicity of polyester fabrics after fluorocarbon finishing, especially when the fabric was pretreated with NaOH and H_2O_2 solutions. Moreover, it was also stated that the obtained highest water repellency levels and the best air permeability characteristics that resulted in noteworthy rise in the substrate hydrophobicity did not display any adverse effect on tensile properties and strength deterioration (Rahmatinejad et al. 2016).

The effects of UV radiation on wool fabrics before the printing process were studied (Millington 2000). UV radiation pretreatment helps to achieve good color yield and brightness. Wool pretreatment is traditionally carried out by an oxidative chlorination process. The gaseous chlorine or dichloroisocyanuric acid is used in this process. However, this process may damage both the fabric and the environment due to the release of the adsorbable organohalogen compounds in the wastewater. For these reasons, the International Wool Secretariat (IWS) prioritizes the development of alternative methods. Alternative chlorine-free oxidative processes for printing preparation may also have commercial application in the pulling and anti-hairing processes of the wool fabric. A special technique, Siroflash, for the preparation before printing for woolen fabric is based on the use of conventional wet oxidation utilizing hydrogen peroxide or permonosulfuric acid (PMS) after continuous ultraviolet (UV) irradiation of the dry wool fabric. In other words, the Siroflash process utilizes this technology following a conventional wet oxidation utilizing hydrogen peroxide or permonosulfuric acid (PMS) after continuous UV irradiation. The main purpose of the Siroflash process is to examine the basic methods of disrupting disulfide bonds of keratin and the possible methods of increasing the degree of fiber damage on the surface of a wool fabric to an equal level with conventional process. UV radiation (especially UV-C, run 200–280 nm) breaks both peptide and disulfide bonds in wool keratin and cannot penetrate the cortex of the fiber cuticle during short-term operations. The Siroflash process comprises the exposure of the wool fabric to UV radiation followed by wet oxidation utilizing chlorine-free oxidants. UV-treated wool fabric results in deeper black shades than non-UV-treated wool counterpart when dyed with 1:1 metal complex dyes. Because hydrogen peroxide is used during the process, the fabric prepared by the Siroflash method is much whiter than the fabric treated with dichloroisocyanuric acid (Millington 1998c).

Chemical changes induced by short-term UV radiation are confined to the fiber surfaces. It was reported that the color changes in wool keratin because of UV radiation have also been observed (Millington 2000). When the wool fabric is exposed to

UV radiation, there are some physical and chemical changes on the wool fiber surface. This process changes the texture of the wool as well as improves gray and black tones. Finally it was also stated that UV curing technology is utilized for the modification of the surface of the wool to help its finishing process (Ferrero and Periolatto 2011).

In the study of Khoddami et al. (Rahmatinejad et al. 2015), the utilization of UV/ozone as an environmentally friendly fast treatment for the surface modification of the wool substrate was investigated. It was reported that both-sided UV/ozone irradiation, in comparison with only one-sided UV/ozone irradiation, led to the slightly better performance as judged for both pad-dry-cure and print-dry-cure fluorocarbon finishing treatments. It was concluded that after the application of this novel method (both-sided UV/ozone modified and then fluorochemical finish treated via the print-dry-cure process) on wool fabric, the inner side of the wool fabric, which was next to the skin, can ensure desirable comforting moisture absorption for human body and protect the human skin from the negative hydrophobic effects of fluorocarbon chains; furthermore, the outer side of the wool fabric displayed highly durable (to repeated washings and abrasion) water and oil repellency characteristics to the outside world, aiding the wool fabric exhibits better dimensional stability with less shrinkage performance after the repeated washings and higher air permeability performance without detrimental effects on the tensile properties (Rahmatinejad et al. 2015).

There are many commercial applications starting from the curing, finishing, color enhancement, and characterization of dyed fabrics with radiation processes. The best known advantages of this technology are improvement of color shades, increasing color fastness and color strength, low cost, and reduction of dye concentration to achieve similar depth of shades (Bhatti et al. 2011). In addition, curing of silk, wool, and cotton can be achieved with this technology. Pilling problem in cotton and wool fabrics can be eliminated with this technology. Besides, the UV technology also can improve the finishing and mercerization processes. Thus, UV radiation has developed the textile material according to ISO, EPA, and FAO standards (Bhatti et al. 2011).

UV Curing

UV light curing process can be applied to the light-dependent polymerization of multifunctional monomers or oligomers. The UV curing process has become a well-accepted technology used in different industrial applications due to its various advantages (Decker 2002; Fouassier and Rabek 1993; Pappas 1992). It is believed that UV curing method is the most effective way of rapidly converting a solvent-free liquid resin to a solid polymer at ambient temperature. Under the intensive light, cross-linking polymerization of acrylate-based resins proceeds in a fraction of a second in order to form a three-dimensional polymer network. The three-dimensional network of polymers exhibits excellent resistance to organic solvents, chemicals, and heat. The cross-linking in this process can easily be obtained by UV (Decker

2002, 1996, 2001). The main benefit of using UV radiation to initiate the chain reaction lies in the very high polymerization rates that can be achieved under intense light. This allows the liquid-to-solid phase change to occur within 1 second (Decker 2002, 1996, 2001).

Photo-initiated polymerization of multifunctional monomers or UV radiation curing was applied in various industrial sectors previously. This technology is now used for ultrafast drying of protective coatings, varnishes, printing inks, and adhesives to produce high-resolution images required for the production of microcircuits and printing plates. Besides, solvent-free formulations provide many advantages such as low-energy consumption (Decker 2002, 1996). Most studies concerning photo-curing have been carried out on the development of highly efficient photoinitiators and highly reactive monomers or polymers. A wide variety of high-performance compounds are now commercially available. Acrylate-based resins, which are polymerized by a radical mechanism, are the most commonly used systems hardening by UV due to their large reactivity (Decker 1996; Siegel 2006). UV curing is typically a process which converts a multifunctional monomer into a cross-linked polymer through chain reaction initiated by the reactive species (ions or free radicals) produced by UV radiation (Decker 1996). Most monomers that are exposed to UV light cannot produce efficient initiators high enough. Therefore, a photoinitiator must be added to the formulation.

There are two main classes of UV-curable resins which vary according to polymerization mechanisms. The first one is the photo-initiated radical polymerization of multifunctional monomers, especially acrylates or unsaturated polyesters. The second one is known as the photo-initiated cationic polymerization of multifunctional epoxides and vinyl ethers (Decker 1996). Radical-type systems are widely utilized in today's UV curing applications due to their higher reactivity (Decker 1996). One of the first UV-curable resins to be utilized in large-scale applications consists of a mixture of unsaturated polyester with styrene and fumaric or maleic structures (Decker 1996). The usage of UV curing process, which is used in different application areas, in textile printing processes is common. The use of UV-curable inks ensures fast drying and increases the speed of processing. For instance, to obtain a high-quality glossy image, UV technology can be used in the last step in which the UV-curable printing varnish is applied (Decker 1996; Siegel 2006; Caiger and Cockett 2000). Because of its many advantages such as low-energy consumption, short startup time, fast and reliable curing process, environment-friendly nature, room temperature curing possibility, and space saving, UV curing technology is used as an alternative to conventional thermal hardening techniques in textile finishing processes like pigment dyeing, coating, and pigment printing (Neral et al. 2006). In an EU project, inkjet printing and pigment printing were applied to textile fabric by UV curing method. Within the scope of this project, the use of a prototype UV scanner was also investigated (Neral et al. 2006). Some of the studies also investigated the suitability of curing of screen printing pigment prints with UV scanner, which is a multifunctional photoinitiator, and the evaluation of UV-treated prints on cotton fabric (Neral et al. 2006). In order to obtain an efficient cure during the UV curing processes, the best possible overlap between the absorption spectrum of the photoinitiator, the transmission spectrum of the pigment, and the emission spectrum of the light is required (Neral et al. 2006).

In the study of Karim et al. *(*Karim et al. 2014*)*, UV-curable inkjet printing was carried out on poly(lactic acid) fabrics. The wavelength of UV radiation during application was 200 nm. Thermally hardened inkjet-printed PLA fabrics were compared with UV-curable inkjet-printed PLA fabrics. It was concluded that UV-curable inkjet PLA fabrics provided better color fastness and show better behavior (Karim et al. 2014).

In another study, radical and cationic UV curing methods were applied to impart water and oil repellency properties to cotton, polyester, and polyamide fabrics. After the application, the polymerization was controlled by the weight increase, while the water and oil repellency properties are determined by the contact angle, moisture absorption, and water vapor permeability angle (El-Molla 2007). UV curing is used not only during printing but also in prepress printing plates. UV technology also reduces the total energy consumption of the process while providing an alternative adaptation strategy to the problem of volatile organic compounds (Decker 1996; Siegel 2006; Caiger and Cockett 2000).

UV curing process is particularly suitable for printing on plastic packages requiring high durability. Therefore, it is applicable not only to conventional cellulosic substrates such as paper and cardboard but also to synthetic polymeric substrates (Caiger and Cockett 2000). UV-curable varnishes are widely utilized to obtain highly durable and resistant coatings for the protection of all kinds of substrates such as wood, plastics, metals, glasses, optical fibers, leather, paper, fabrics, etc. So, the viscoelastic properties of the cured coating are particularly designed to suit the characteristics of the substrate (Decker 1996). Hard and scratch-resistant, aromatic polyether and polyester-based coatings are utilized for surface protection of hard substrates such as metal and organic glass. Low-modulus polyurethane elastomers, which exhibit good corrosion and impact resistance, are required to maintain flexible supports. UV curing adhesives are used for laminating the two parts. Thus, a rapid pressure-sensitive adhesion is achieved. UV-curable systems provide pollution control, economic gain, and high performance (Decker 1996).

The Use of UV Technology to Prevent Pilling Problem

Surface phenomena such as shrinkage or puckering occur during the use and washing of garments. In addition to dyeing processes, shrinkproof processes are the most common chemical processes applied to textile materials made from wool fibers. Pilling also occurs on the surface of the fabric during use. Pilling is a small surface fiber ball and is a physical problem sometimes consisting from the fibers containing contaminants. Chlorination is the most commonly used process to prevent felting and beading of the wool fabric. Recently, concerns about the release of adsorbable organohalogens (AOX) into the environment during this process have been increasing. Alternatively, these environmental concerns lead to the development of AOX-free processes. In addition, different radiation techniques such as ultraviolet and plasma can be used as an alternative to chlorination in the wool processing (El-Sayed and El-Khatib 2005). There are many processes to decrease pilling, but no process could guarantee zero pilling in wear (Millington 1997, 1998a, b).

In a study conducted by K. R. Millington, it was suggested that UV radiation could remove the pilling problem for knitted wool and cotton fabrics (Millington 1998b). In 1998, Millington developed a method of exposing the fabric to ultraviolet radiation, followed by a mild oxidation process utilizing hydrogen peroxide or permonosulfuric acid. This method developed for knitted fabrics is called Siroflash anti-pilling (El-Sayed and El-Khatib 2005; Millington 1997, 1998a, b). The fibers on the fabric surface are exposed to UV-C radiation, and then the wet oxidation process applied sensitizes surface fibers. As the surface fibers are much weaker after the applied process, the beads on the fabric surface cannot hold onto the fibers leading to a decrease on pilling problem. This process is a very effective and chlorine-free method to prevent pilling in wool knitted fabrics.

A variation of the Siroflash processes is also applied to cotton and cotton/wool blend fabrics. Hydrogen peroxide is applied to the fabrics before the fabrics were exposed to the UV radiation. It is then treated with continuous UV irradiation with a medium-pressure arc system akin to those utilized commercially for UV curing of polymer films. This process, which is a variation of the Siroflash process, is ineffective on pure wool knitted fabrics. Low-power antiseptic UV tubes are used to provide an effective treatment on wool knitted fabrics. Irradiation time is also very important in this process. The irradiation times vary depending on the fabric construction. Stronger UV sources providing high levels of UV-C radiation can provide fast, effective, anti-pilling treatment for wool. Also, a protease enzyme with UV/H_2O_2 can also be used to attenuate surface fibers (Millington 1997, 1998a, b). After this process, wool and cotton knitwear pilling problem had eliminated from the surface of the fabric by UV radiation treatment without affecting the strength of the fiber (Bhatti et al. 2011; Kim et al. 2005). Also, the wool fabric characterization conforms to the standards established by ISO. For this reason, the continuous UV irradiation of the fabric followed by batch oxidation is of a great commercial value (Millington 1997, 1998a, b).

Conclusions

It is possible to create both functional and artistic designs by using different materials and different techniques together in the textile industry. But it is very important that applied process types should not harm the environment and living things. One of the issues that have come up recently is sustainable textile design. As a result of the developments in today's world, companies invest in technology in order to provide competitive advantage in many sectors and to increase environmental awareness. Textile industry should re-design their processes in order to reduce the potential environmental damage leading to more sustainable planet. Moreover, increasing competition between the companies enhances their interest in the utilization of novel technologies such as ultraviolet technology in their textile processes. Thus, while the quality of their products and services may increase, their potential hazardous damage to the environment could be diminished and/or eliminated. Therefore, in textile finishing processes, many scientific studies have been carried out on energy-, water-, and time-saving technologies such as plasma, ultrasound, enzyme, ozone, microwave, nanotechnology, and ultraviolet (UV) technology in pretreatment, dyeing, printing, and finishing processes. For instance, the usage of UV technology offers so much positive attributes to the textile production and design and also provides sustainable and eco-friendly opportunities for many different areas of the textile industry. UV technology, which is one of these technologies, is applied in medicine, food, cosmetics, and other sectors. Some studies in the literature emphasized that the applications of UV technology in textile sector can increase the productivity of production. The environment-friendly nature of ultraviolet technology is also very important in terms of sustainability. It also provides an advantage in the process of creating the desired pattern and design. The use of UV technology in decolorization and purification of textile wastewaters, as pretreatment and surface modification processes prior to coloration processes, for UV curing process, and for pilling problem prevention are some of the examples of the successful contribution of UV technology to sustainable textile production and design. UV technology, which is especially important for textile sector, can widely be used in curing applications. In addition, the functions of UV technology on different textile materials (e.g., the prevention of shrinkage and pilling in wool fabrics) are also supported by experimental studies. We understand that the use of UV technology in textile processes has been developed day by day. It was shown that UV technology increases the production efficiency in textile sector. Bleaching processing can be performed in a shorter time with the help of UV technology. For instance, the best whiteness levels could be obtained with H_2O_2/UV treatment. Short-wavelength UV rays provide the surface modification of woolen textile materials in particular and thus give advantage to the dyeing process of textile material (as a premodification process prior to dyeing and printing processes). In addition, the development of both aesthetic and functional effects can be enhanced through UV technology. It allows creating more vivid areas in coloration. Thus, it is easier and cleaner to create different patterns and designs on the textile material. In the future, it is predicted that many dry and clean technologies such as UV technology will be used more and more frequently for design purposes since the sustainability in design and fashion is gaining more and more importance day by day.

Current studies show that UV technology will be used more actively in sustainable textile process design in the near future. The only way to bring functionality to design products will be better understood by incorporating new technologies into process designs. It is thought that designs inspired by artistic textiles can be brought into production and industry by adding different values with sustainable UV technology in production processes. It is very important to use UV technology in premodification processes in this field. Since UV technology affects dye uptake of textile materials, the usage of UV technology may create differences in coloration. Thanks to the use of UV technology in textile process design, it is envisaged that the variety of textile products developed for completely different purposes will increase and their usage areas will be increased leading to more sustainable future.

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