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Radiation Effects in Textile Materials

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Abstract

Irradiation processes have several commercial applications, in the coating of metals, plastics, and glass, in printing, wood finishing, film and plastic cross-linking, and in the fields of adhesive and electrical insulations. The advantages of this technology are well known.

Radiation treatment on fabric and garments can add value in coloration, antifelting, printing, and coating. In this chapter, different irradiation methods such as plasma, electron beam, laser, ion implantation, microwave, gamma, and ablation are described, and the effects of these process in textile industry as a finishing method are discussed and compared with conventional methods.

Keywords: Irradiation, Fabric, Textile, Material, Finishing

1. Introduction

The advancement of technology in the textile market has led scientists and researchers to develop novel finishes to add high value on deferent textile materials. It was a new window for researchers to advent and explore new research fields which include geotextiles, flame retardant textiles, insect repellent textiles, aroma textiles, medical textiles, smart textiles, antibacterial textiles, and nanotextiles, etc.

Recent developments in the textile industry are mainly focused on physical and chemical modifications on surface of fibers and fabrics. Different chemical and biological methods have been used electively to improve or impart permanent functional properties on the surface of textile materials. However, some of these chemicals are toxic and sometimes expensive [1].

Alternatively, radiation technology involving low energy use, no chemicals, ease to handling, and high treatment speed can modify the surface of textiles and improve dye uptake, printing, fastness properties, adhesion of coatings, and adsorption of used chemicals.

In this chapter the effect of ultraviolet (UV), gamma, plasma, laser, microwave, electron beam, ion beam, ultrasonic on surface, chemical, and physical and mechanical properties of textile materials is fully discussed.

2. UV irradiation and its application in textile industry

One of the effective and economical methods of surface modification for both natural and synthetic polymers is UV irradiation. Excitation and dissociation of the polymeric molecules take place during exposing the surface to the UV treatment, which is known as a photosensitized oxidation process.

The color depth of the polylactide (PLA) and polyethylene terephthalate (PET) fabrics has been increased by the UV irradiation. This increase in the depth of dyeing is believed to be due to the surface roughening of the fabrics produced by the UV [2].

According to previous research work which has been done, the prepared thin film polyamide nanofiltration membranes were modified by acrylic acid (AA) and UV irradiation. The effect of UV-irradiation time and addition of AA on the performance and morphology of nanofiltration membranes were investigated. The obtained membranes illustrate the ability for rejection of Na_2SO_4 and significant properties for separation of divalent ions from monovalent ions [3].

In recent years, many methods have been reported for modifying PET fabric to be hydrophilic. Different types of chemical auxiliaries can be used for this purpose. However, the hydrophilicity of the treated PET surface is not durable because the coated hydrophilic material easily dissolves during repeated washes. Photo-chemical reactions and photophysical processes are gaining attention as techniques for modifying the surface of PET fabrics [4].

UV irradiation and treatment with nano- TiO_2 , H_2O_2 , and NaOH increased the hydrophilicity of PET fabric, with an irradiation time of 30 min making the fabric nearly wettable and an irradiation time of 40 min making the fabric superhydrophilic. The greatest and most durable wettability results were obtained after 40 min of UV irradiation combined with 30 g/L nano- TiO_2 , 50 g/L H_2O_2 , and 30 g/L NaOH treatment. The excellent mechanical and physical properties of PET fabric were retained after modification, although the breaking strength and elongation were slightly reduced. The induced hydrophilicity of the PET fabric can be considered permanent because the surface of the PET fabric was chemically modified with the introduction of hydrophilic groups [4].

In the other research, a new technique has been presented to graft sulfonic groups at the surface of PET fabric, which is based on UVC treatment with SO_3 gaseous molecule. These modifications improved the hydrophilic character of PET fabric surface and consequently its dyeing

ability. The Schematic of system is shown in **Figure 1**. The air flow containing fuming SO molecules is injected into the vessel between which is composed of an UVC lamp and the fabric to be treated. The UVC lamp emits intense and nearly monochromatic light (254 nm). In fact, the UVC lamp emits 512 kJ mol^{-1} per photon, which allows the PET fibers functionalization without damaging their bulk properties. Sulfonic (SOH) groups can be introduced into aromatic compounds through an electrophilic substitution reaction. Such a reaction is referred as sulfonation [5].

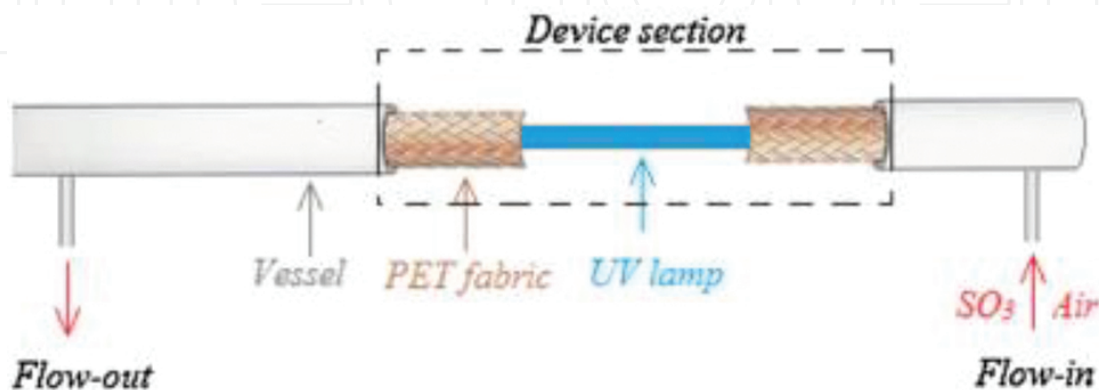


Figure 1. UVC treatment device [5].

The results reported in the other research demonstrate that the UVC (254 nm) irradiation method under a stream of gaseous Cl has the potential to graft PET textile fabrics. This technique has many advantages, such as easy handling, and it is a cheap, solvent-free continuous process without changing the bulk properties. The medication involves only a few nanometres of the surface. Several analytical techniques have confirmed that surface chlorination has occurred. Scanning Electron Microscope (SEM) analyses showed that the chlorination only occurred at the surface of the fibers without changing the bulk of fibers. The Differential scanning calorimetry (DSC) thermograms indicated that the thermal characteristics of the PET fabrics were maintained. X-ray photoelectron spectroscopy (XPS) also showed the presence of Cl atoms in the upper molecular layers of the surface. The affinity of modified fabrics to cationic dyes is more than untreated samples [6].

For a long time, the textile industry has been searching for a rapid way to modify textile polymer surfaces. Obtaining good bonding between two dissimilar materials is critical for several aspects in textile finishes processing. Adhesion between PET and Tuftane Thermoplastic Polyurethane (TPU) Film was improved by grafting NCO groups onto the PET surface using UV irradiation process by Dong Liu and his coworkers [7].

3. Gamma irradiation on textile fabrics

Gamma rays are high-energy electromagnetic radiations having energies above 100 keV and wavelengths less than 10 picometers. Surface modification of textiles using gamma ray is one of the promising methods.

The excellent mechanical properties, heat and oxidation resistance, and environmental stabilities make carbon fiber fabrics ideal reinforcing materials in the advanced composite fields, such as solar panel of space station and electric vehicle body. All these excellent properties depend largely on the interfacial adhesion which finally affects the overall property of the resulting composites. Recently, radiation-induced grafting has been extensively applied as a competitive methodology to develop new functional materials. An easy method to evenly functionalize the fabric surfaces by γ -ray irradiation grafting was reported. This novel technique is simple, green, and versatile. The functionalization was much more uniform compared with the traditional electrochemical method. The interfacial strength of the composites had a dramatic increase [8].

Presently, polymeric membranes are extensively employed in the field of biomedical materials contacting with blood. Sulfonated polypropylene nonwoven fabric (PPNWF) has been successfully prepared via gamma-ray preirradiation-induced graft polymerization of sodium styrenesulfonate (SSS) and acrylamide (AAm) by li et al (Figure 2).

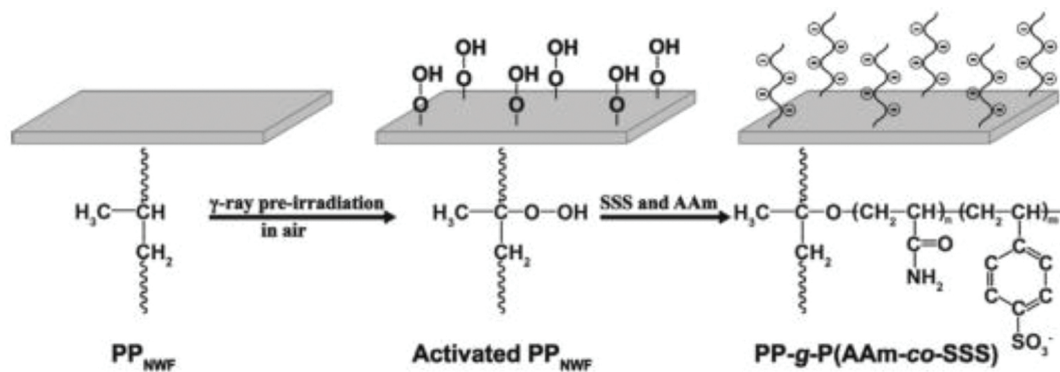


Figure 2. Schematic diagram of preparing sulfonated PP_{NWF} via gamma-ray preirradiation method [9].

Gamma ray preirradiation-induced cograft polymerization has been extensively applied to modified polymer materials because of its simple procedure and even grafting. Acrylonitrile (AN) has been widely used in the modification of materials and an amidoxime group can be obtained by further chemical treatments from the nitrile group to increase adsorption efficiency for heavy ions. In a research that has been done in 2013 by Liu and his coworkers, a preirradiation-induced emulsion cograft polymerization method was used to introduce AN and AA onto a PE nonwoven fabric. The use of AA is meant to improve the hydrophilicity of the modified fabric. The modified nonwoven fabric is ready for further amidoximation to the application of heavy metal ion extraction [10].

In the other research, SSS was grafted onto PPNWF via γ -ray coirradiation method with the existence of *N*-vinyl-2-pyrrolidone. The modified PPNWFs presented good blood compatibility, such as lower hemolysis rate and lower platelet adhesion. Besides, the modified PPNWFs prolonged the clotting time and presented excellent anticoagulant effect [11].

The textile industries are one of the major sources of water pollution in terms of releasing highly colored waste stream in surface water bodies. The wastewater generated in textile

processing plants is contaminated with toxic synthetic colorants and various perilous chemicals. The main objectives of the study by Bhuiyan et al. were to degrade the dye molecules and organic pollutants of textile wastewater by using gamma irradiation followed by the investigation of physicochemical parameters of the irradiated water as well as looking into the scope for using treated wastewater for irrigation and dyeing purposes. The wastewater samples were submitted to Cobalt-60 gamma radiation source.

The irradiated wastewater was found to be recyclable in textile wet processing and reusable for irrigation purposes [12, 13].

The presence of toxic metals and pathogenetic microbes in drinking water is a potential health risk. Consequently, numerous investigations have been carried out on the functionalized polymer membrane with AgNPs as effective antimicrobial agents for water treatment. Unfortunately, the AgNPs were commonly inert with polymer surfaces so that silver releases into water filtrate in an overdose compared to the permitted limit of standard at maximum of 0.1 mg/L, according to the US Environmental Protection Agency (EPA) and World Health Organization (WHO).

A new method to immobilize AgNPs onto the acrylic grafted polyethylene nonwoven (PE) fabric by gamma Co-60 irradiation for drinking water treatment has been described in 2013.

The PE fabric pieces were treated by a mixture of acetone/H₂O solution and dried before irradiation. The PE fabric samples were irradiated at the required doses up to 50 kGy by γ ray from Co-60 source. Thereafter, the graft reactions were carried out at $\sim 90^{\circ}\text{C}$ in a flask containing 1 g preirradiated PE, 0.05 g Mohr's salt and AA with concentrations of 10–50% (v/v) in 100 ml aqueous solution. The PE-g-PAAc samples were soaked overnight at room temperature in Ag NPs colloidal solutions and then squeezed to remove the excess Ag NPs, rinsed with pure water and dried in an oven at 70 C for 2 h. The dried fabrics were then annealed at 120 C for 1 h for esterification of –COOH group of PAAc with –OH group of Polyvinyl alcohol (PVA). The prepared fabrics contained about 10,000 ppm Ag NPs showing strong bactericidal efficiency against *Escherichia coli*. Based on the strong bactericidal efficiency and under permitted limit of silver release into water filtrate, PE-g PAAc/Ag NPs fabrics can be used for the treatment of drinking water. Also, this kind of filters can be used in air cleaners and have other applications [14].

In the other research, the silver ions have been reduced effectively by gamma irradiation and immobilized on the cotton fabrics by in situ synthesis. The Ag NPs content deposited on the fabrics was of 1696 mg/kg, when the fabric sample was irradiated in 1.5 mM Ag NO and 1.0% chitosan solution at the dose of 13.8 kGy at 30°C.

Antibacterial efficacy of the Ag NPs fabrics after washing 40 cycles of washing was about 99.99% for *Staphylococcus aureus* and *E. coli*. The AgNPs/cotton fabrics washing from 1 to 40 cycles were innocuous to skin ($k = 0$). These results confirm that gamma irradiation of cotton fabrics in the presence of AgNO and chitosan solution is a promising approach for preparation of stable, safe, and efficacious antibacterial fabrics [15].

In the past decades, the materials with high water and oil repellency have attracted much attention from researchers and industries. The perfluoroalkyl phosphate acrylates have been

grafted onto a cotton fabric via gamma-ray irradiation to improve the hydrophobic and oleophobic properties.

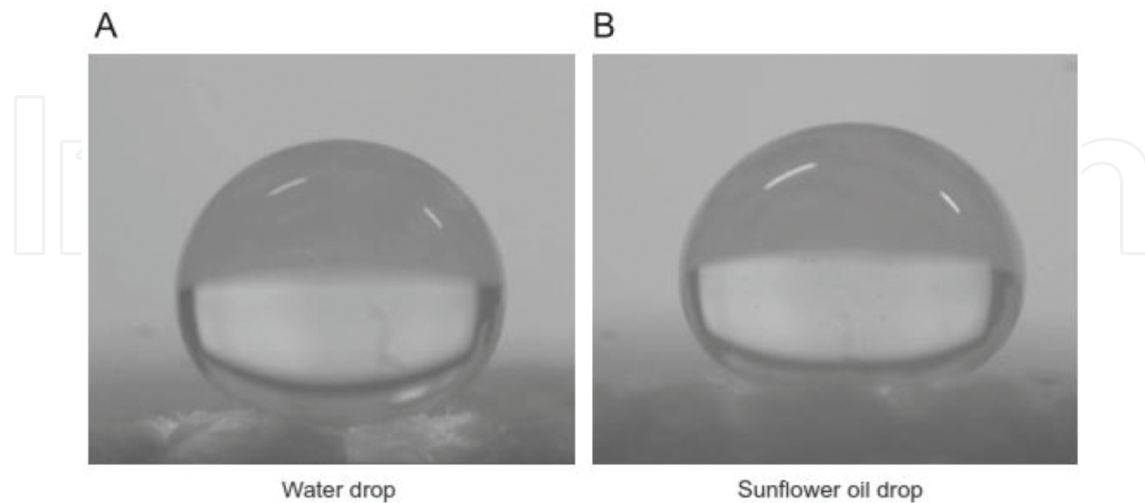


Figure 3. Photographs of water and sunflower oil drops on the grafted sample [16].

The results show that the fabric became highly hydrophobic and oleophobic with the contact angles of above 150° and 140° for water and sunflower oil, respectively (**Figure 3**) [16].

In the other research, a novel coating formulation for improving the UV protection property on cotton, PET, and cotton/PET fabrics was prepared, and gamma rays were applied for surface curing. Aluminum potassium sulfate (Alum) was used individually and in binary coat with Zinc Oxide (ZnO), to induce the UV-blocking properties [17].

4. Microwave applications in textile industry

Microwaves comprise electromagnetic radiation in the frequency range of 300 MHz–300 GHz. As the polar or charged particles in a reaction medium fail to align themselves as fast as the direction of the electric field of microwaves changes, friction is created to heat the medium [18].

They can penetrate into a material and heat the deep layers of the material strongly when they release their energy. Microwave irradiation offers a number of advantages over conventional heating methods, including using less energy, offering a higher heating rate, and offering the ability to more quickly start and stop heating.

Sulfonating a PET fabric by dilute sulfuric acid and microwave irradiation has been found to produce a super-hydrophilic PET fabric, and the fibers sustained minimal damage.

PET fabric has been immersed in H_2SO_4 solutions with different concentrations at room temperature for 5 min.

PET fabric samples were then dried at 50°C for 30 min and then irradiated with microwaves at 2450 MHz using a commercial 700 W microwave oven for 4 min. The SEM images of both

untreated and treated PET are shown in **Figure 4**. The surfaces of the original and the modified PET fibers are all smooth.

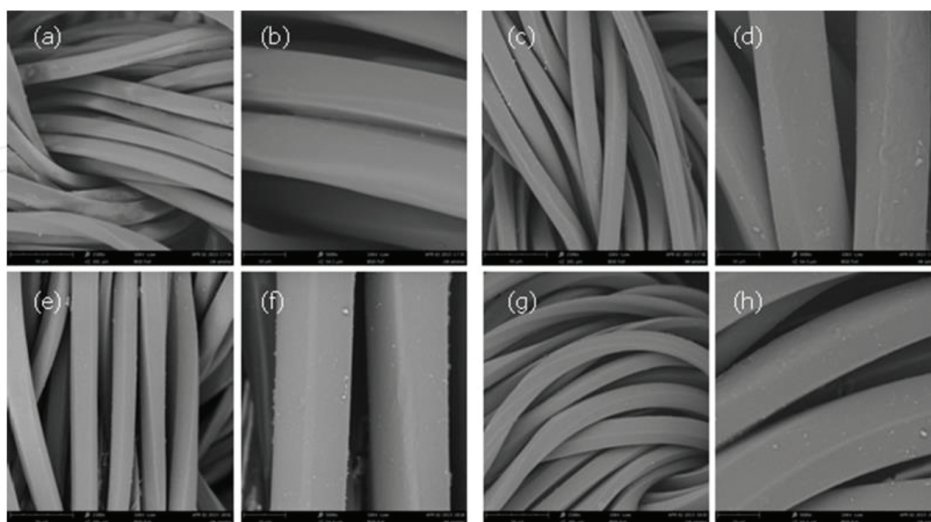


Figure 4. SEM images ($\times 1500$ and $\times 5000$) of (a, b) the original PET fibers; (c, d) PET fibers modified by 10 g/L H_2SO_4 ; (e, f) PET fibers modified by 20 g/L H_2SO_4 ; and (g, h) PET fibers modified by 25 g/L [19].

Microwave modification process is quick and inexpensive. Therefore, the modification process could be used in a wide range of applications [19].

Polyamide 66 (PA 66) is one of the most abundantly used fabric in many areas attributed to its low cost, resistance to shrinkage, abrasion, etc. However, its combustibility and serious dripping produced during combustion cannot meet industrial and civil requirements in many cases. Zhao et al. researched the efforts on surface modification of PA 66 fabric by microwave-induced grafting with 2-hydroxyethyl methacrylate (HEMA). The grafting reaction was undertaken in water solution to decrease the damage of fabric. The hydrophilicity, dripping tendency, and mechanical properties of grafted samples have been significantly improved. However, the slight change of limiting oxygen index (LOI) values and high damaged length during burning cannot meet the flame retardant requirements in many fields [20].

Microwave (MW) energy which is used in dyeing of various types of textile staple and fixation processes has brought positive results. Microwave irradiation increases the diffusion of dye molecules in dyeing process when applied to both synthetic and natural fibers. It is also used in prefinishing of silk yarns. In addition MW energy is accepted as more efficient than conventional methods for cotton fabric finishing, drying, and curing processes, durable press finishing, incombustibility, water and oil repellent finishing [21].

5. Ultrasonic in textile industry

Ultrasound technology is among the irradiation technologies whose applications in different branches of industries have soared in recent years.

Ultrasound technology has been extensively used for detecting defects in a large variety of industrial components and materials. Using ultrasound waves through the air is not the first choice due to the high impedance mismatch between air and most of transducer and component materials. As a result, a higher impedance substance is employed as a couplant to optimize the acoustic energy transfer to the sample, for example, water or a coupling gel. Nevertheless, in some processes, it is not allowed to use a wet coupling, which makes room for a specific category of applications usually named as noncontact or airborne ultrasound. An example of this is the inspection of textile goods, where a wet coupling substance could degrade the fabric and/or slow the manufacturing process.

Several previous investigations have shown that ultrasonic technology enhances mass transfer during some textile processing steps such as desizing, scouring, bleaching, mercerizing, and dyeing of natural fabrics.

Pazos-Ospina et al. in 2015 presents a design methodology for half-curved airborne ultrasonic arrays based in cellular ferroelectret film. The geometry of the array proposed allows them focus naturally in the vertical plane and electronically in the horizontal one, obtaining similar spatial resolution in both directions. Theoretical predictions and simulated results were validated with a developed array prototype designed to operate at frequencies between 50 kHz and 300 kHz. The potential of the device was shown by inspecting different textile samples in transmission mode. This multi-transducer design is a low-cost alternative to the use of composite 2D arrays in noncontact ultrasonic inspections [22].

Cleaning of materials is one of the most important applications of ultrasound. However, the use of ultrasonic energy for textile washing has been searched many years without achieving commercial development. The cleaning action of ultrasonic energy is due to cavitations. The implosion of vapor bubbles inside the cleaning auxiliaries and near the surface to be cleaned imposes such stress on the surface that erodes the contaminant and removes the impurities. On the other hand, stable cavitations, may also cause the dispersion of the particles of contaminant removed from the surface.

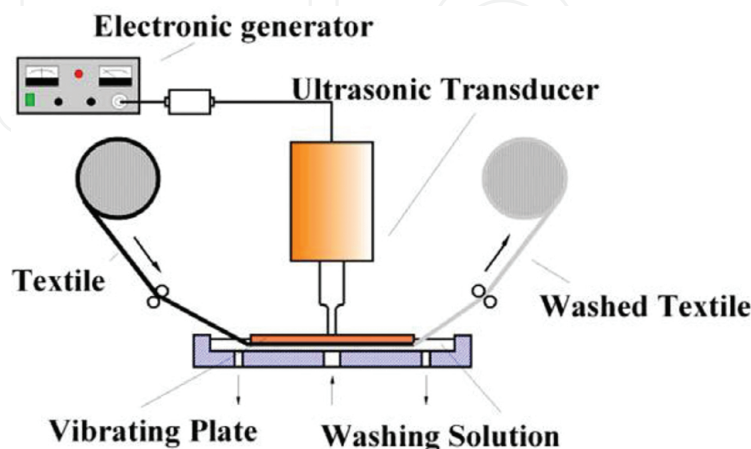


Figure 5. Basic scheme of the ultrasonic process [23].

An ultrasonic system for the continuous washing of textiles in liquid layers based on a procedure has been designed and constructed by Gallego-Juarez et al. in 2010. The system incorporates, as the main part, special plate transducers capable for high-power operation without the interaction of perturbing undesired vibration modes. This system has shown very good washing behavior either with the laboratory or the semiindustrial set-up (**Figure 5**) [23].

Recently, attempts have been made to use acoustic cavitation for washing textiles. Ultrasonic cleaning has been widely employed to remove submicron-sized contaminant particles adhering to solid substrates (e.g., photo masks and wafers) in semiconductor industry. Ultrasonic waves traveling in a liquid result in cavitation and thus produce bubbles. The bubbles exhibit rich dynamic behaviors such as translation, oscillation, growth, and collapse in response to the varying acoustic pressure [24].

In the recent decade, the application of ultrasonic irradiation as an advanced oxidation process has attracted much attention because of the generation of high amounts of $\bullet\text{OH}$ radicals due to the ultrasonic cavitation. The ultrasonic waves result in the rapid growth and subsequently, collapse of the cavitation bubbles, which produces extremely high pressure (up to 1800 atm) and temperature (as high as 5000 K) in the bubbles. The high temperature, together with the high pressure, named "hot spots" leads to the generation of $\bullet\text{OH}$ within the gas-liquid transition zone near the bubbles and bulk solution as a result of the water dissociation. It has been demonstrated that the catalytically enhanced ultrasonic irradiation based on the application of semiconductors, known as sonocatalysis, has higher degradation efficiency and lower processing time than that of sonication alone.

Darvishi Cheshmeh Soltani et al. in 2016 used a porous clay-like support with unique characteristics for the synthesis and immobilization of ZnO nanostructures to be used as a sonocatalyst for the sonocatalytic decolorization of methylene blue (MB) dye in the aqueous phase. They concluded that the sonocatalytic activity of ZnO-biosilica nanocomposite (77.8%) was higher than that of pure ZnO nanostructures (53.6%). Increasing the initial pH from 3 to 10 led to increasing the color removal from 41.8% to 88.2%, respectively. Increasing the sonocatalyst dosage from 0.5 to 2.5 g/L resulted in increasing the color removal. They also concluded that the ZnO-biosilica nanocomposite can be a suitable sonocatalyst for the sonocatalytic decolorization of colored solutions with high reusability potential and cost-efficiency [25].

As an alternative to the existing finishing technologies, a facile one-step sonochemical route has been suggested for uniform deposition of inorganic nanoparticles on the surface of solid substrates, including textiles.

The antimicrobial finishing is very important for medical textiles, decreasing the risk of hospital-acquired infections.

Petkova et al. in 2016 report a simultaneous sonochemical/enzymatic process for durable antibacterial coating of cotton with zinc oxide nanoparticles (ZnO NPs). The novel technology goes beyond first enzymatic preactivation of the fabrics and subsequent sonochemical nanocoating and is designed to produce "ready-to-use" antibacterial medical textiles in a single step.

A multilayer coating of uniformly dispersed NPs was obtained in the process. The pretreatment with enzymes causes better adhesion of the ZnO NPs on the surface of cotton fabrics. The NPs-coated cotton fabrics inhibited the growth of *S. aureus* and *E. coli*, respectively, by 67% and 100% [26]

Textile dyeing assisted by ultrasonic energy has attained a greater interest in recent years. Ultrasonic-assisted dyeing of cellulosic fibers has already proved to be a better choice among conventional dyeing by many researchers.

Khatri et al. in 2016 reported ultrasonic dyeing of nanofibers. They chose cellulose nanofibers and dyed with two reactive dyes, CI reactive black 5 and CI reactive red 195. Results revealed that the ultrasonic dyeing produced higher color yield (K/S values) than the conventional dyeing. The color fastness test results depicted good dye fixation. Also they have reported that ultrasonic energy during dyeing does not affect surface morphology of nanofibers. The results conclude successful dyeing of cellulose nanofibers using ultrasonic energy with better color yield and color fastness results than conventional dyeing [27].

6. Laser in surface modification of polymer and fabrics

Laser modification on material surface is one of the most studied technologies. It has been shown that various materials modified by laser irradiation often exhibit physical and chemical changes in the material's surface. In general, laser irradiation could not affect the bulk properties of a polymer due to its low penetration depth (**Figure 6**) [28, 29].

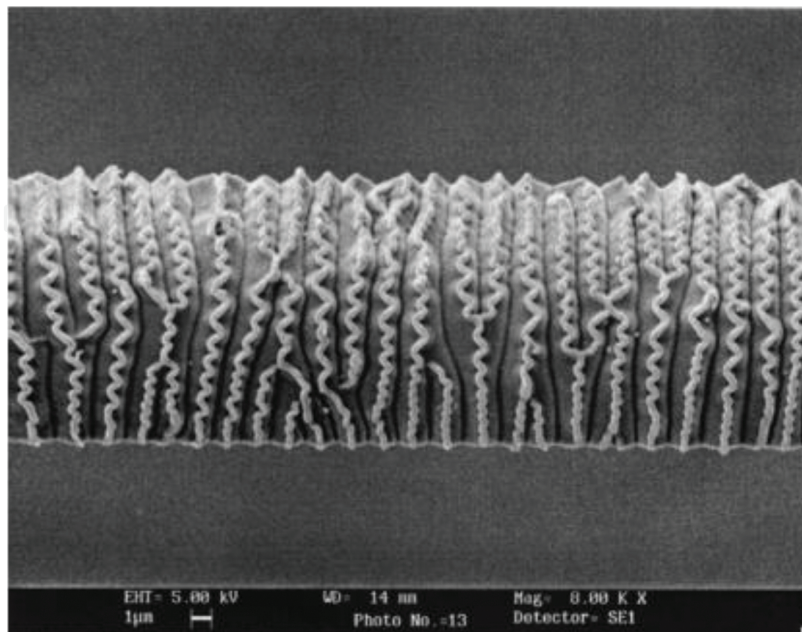


Figure 6. Surface structure of polyester fiber under high fluence (5 pulses at 100 mJ/cm²) [28].

In the research which has been done by Bahtyari, the effect of CO₂ laser treatment on the dyeability of polyimide fabrics reveals that, following laser treatment, the dyeability of polyamide increased significantly. This is accompanied by a significant bursting strength loss.

It has been observed that, as the laser modification of the fabric was carried out with low intensity, the concentration of free amino groups, which are necessary during dyeing with acid and reactive dyes, increased [30].

The modification induced in PLA by the ArF excimer laser radiation has been investigated by Rytlewski et al. It was found that the surface energy change was affected by surface oxidation as well as by surface roughness. ArF laser surface treatment can be an effective way of improving PLA adhesion properties [31].

Another article focused on the development of a laser pretreatment method for glass-fibre-reinforced polypropylene surfaces for industrial applications. The aim of this research is to create a surface for bonding polypropylene which adheres very poorly to most of the materials and forms to the matrix material for plastic composites [32].

On the other hand, as is known, the laser is a source of energy which can be used for irradiation of different substrates and its power and intensity can be easily controlled. By using laser, it is possible to cut a great variety of material from metal to fabric. Also it would be possible to transfer certain designs onto the surface of textile material by changing the dye molecules in the fabric and changing the color quality values by laser irradiation of fabrics at reduced intensity (**Figure 7**) [33].



Figure 7. Some examples of denim trousers designed by laser beam method [33].

The CO₂ laser-thinning method has been applied to the PET fiber to prepare the PET nonwoven fabric without using the solvent by Suzuki et al.

The obtained nonwoven fabric was made of continuous microfibers with a uniform diameter without a droplet.

The laser-thinning method has been found to be effective for producing other nonwoven fabrics such as poly(L-lactic acid) and poly(glycolic acid). The schematic of setup is shown in **Figure 8** [34].

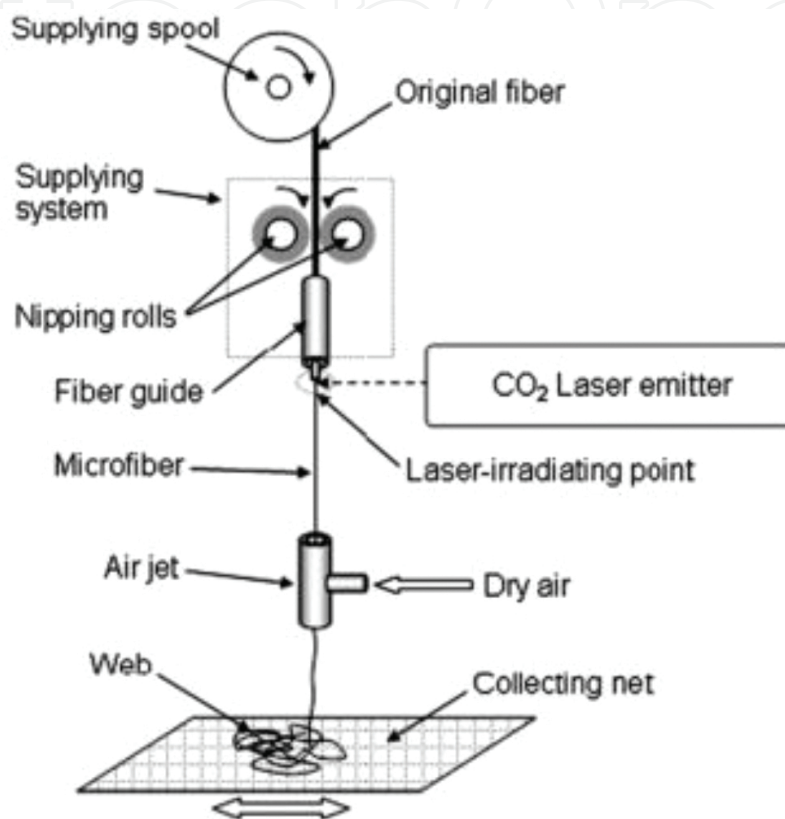


Figure 8. CO₂ laser-thinning apparatus used for web formation [34].

CO₂ laser treatment was used as a novel method for creating antibacterial properties on glass mat by Wiener et al. in 2014. Various types of metallic salts such as CuO, ZnO, and AgNO₃ were applied on surface of glass mat and irradiated with the laser light beam (100 μ s). Metal particles were deposited on the surface of samples. The antibacterial properties of the fabrics were connected with the presence of metal particles on their surface. Wiener et al. concluded that the change in properties induced by laser can effect an improvement in certain textile products [35].

Glass fiber mat surface modifications were carried out using CO₂ laser. The geometry of the experiment is visualized in **Figure 9**. In the laser tube (1) produces IR laser beam (2). In the direction of laser beam, computer-adjusted mirror is located (3) which determined the position of irradiated place on glass fiber mat (4). The temperature of the glass fiber mat on its irradiated side cannot be measured due to high intensity of IR laser beam. So only the temperature of back side of glass fiber mat was estimated (5) by infrared thermometer (6). Laser light treatment

of glass fiber resulted in interesting properties based on the mechanical properties, such as strength, modulus, and elongation of the glass fiber mat, the permeability, morphological properties, and the thickness.

Wiener et al. in 2014 concluded that by increasing the laser intensity, the strength and modulus of the mat decrease. But in the case of laser cycling treatment, the mechanical properties are improved. We observed that laser treatment causes increase of porosity and better air permeability [36].

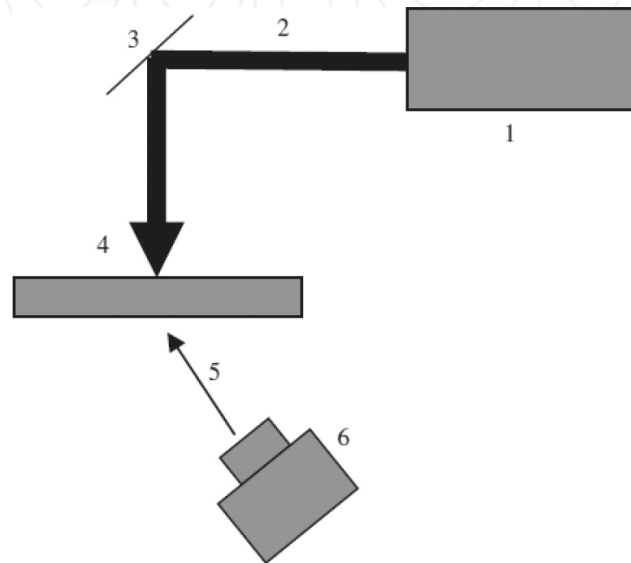


Figure 9. Schematic view of the laser treatment of glass fiber and temperature measurement [36].

7. Plasma and its application in textile industry

Plasma technique can have very important effects on the properties of textile materials. Different types of plasma gases have different effects on the surfaces of textiles. Plasma has many potential for the activation and functionalization of textile materials. Plasma technology is slow but steady in the industrial revolution. Surface modification of textiles cannot replace all wet processes, but it can be a viable pretreatment, which can provide plenty of environmental and economical benefits. Therefore, textile industry should consider the concept of higher initial investments in equipment that will be paid off quickly with respect to environment-related savings and the profit of the sale of high value-added products [37–39].

Improving the fastness properties and antibacterial activity of dyed cotton samples was studied by Shahidi in 2015. In her research, first cotton fabrics were dyed with various types of dyestuffs such as Direct, Vat, and Reactive. Then prepared samples were sputtered using plasma sputtering system for 15 s by silver and copper. For deposition of metal nano layer on the surface of samples, DC magnetron sputtering system was used. Samples were placed on the anode. By attacking active ions, radicals, and electrons, the cathode particles were scattered.

Silver or copper particles were deposited on the surface of cotton samples, and through incorporation of metal nano particles on fabric surfaces, the antibacterial has been developed. It can be concluded that sputtering technique can be a novel method for improving the fastness properties of dyed cotton samples [38].

DC magnetron sputtering system for creating antibacterial and ultraviolet protective cotton fabrics has been used by Shahidi et al. in 2016. A silver anode and cathode were used. Silver particles were deposited on the both sides of cotton samples, and the antibacterial property has been developed, through sputtering of silver particles on fabric surfaces. Treated cotton fabrics had an excellent UV-blocking property. According to the standard, the treated cotton fabric can claim to be a "UV Protective product." They concluded that the change in properties induced by plasma can effect an improvement in certain textile products [39].

Conventional wet treatment in textile industry involves high consumption and pollution of water resources. Wastewater processing costs are high, and drying the wetted fibers is energy-, time-, and cost-intensive. So the textile industry has a great interest in alternative dry processes. Low temperature plasma treatment is a dry and ecofriendly technology which has been widely used to modify the chemical and topographical properties of polymers and textiles surface. The application of plasma technologies as a pretreatment and finishing process for textiles has become very popular because this surface modification method changes the outermost layer of the substrate without altering the bulk properties. Low-pressure plasma treatments are known to induce physical and chemical surface changes in textile fibers through several concurrent processes (activation, etching, grafting chemical functional groups, and cross-linking).

Girmoldi et al., in 2015, performed atmospheric pressure plasma treatments of pure cashmere and wool/cashmere textiles with a dielectric barrier discharge (DBD) in humid air (air/water vapor mixtures). Their analyses revealed a surface oxidation of the treated fabrics, which enhances their surface wettability with minor etching effects, an essential feature for the maintenance of the textile softness [40].

Air plasma treatment can modify the physical and chemical properties of the surface, and it causes to increase the hydrophilic character of a material. The production of new textile products for cosmetic applications requires pretreatment on the surface of fabrics. In this kind of application, the textile must have some organoleptic and aesthetic properties which require the use of softeners.

Surface modification of the PA66 fibers by low temperature plasma has been studied by Labay et al. in 2014. Corona plasma treatment has been investigated to achieve surface modification in the first nanometers of polymer fibers surface in order to modulate the incorporation and the release of caffeine. Plasma treatment improved the caffeine release [41].

Polyester fiber is one of the most important materials for textile manufacturing. However, the conventional antistatic finishing processes for polyester involve numerous energies and chemicals, with corresponding environmental pollution. The synergetic effects of low-temperature oxygen plasma (P) and N,O-carboxymethyl chitosan (N) treatments on the antistatic and antibacterial properties of polyester fabrics were investigated by Liu et al. in

2016. They concluded that all the treated polyester fabrics had no obviously antibacterial effect on *E. coli* (Gram-negative). Their findings indicated that the proposed process can provide good antistatic performance for polyester fabrics with a minimum of pollution [42].

In 2016, pure cashmere and wool/nylon textiles were modified by means of an atmospheric pressure plasma treatment with a DBD in humid air followed by a finishing process with a fluorocarbon resin by Zanini et al. Their result indicated a higher amount of fluorocarbon resin on the surface of the fabric which was plasma treated before the finishing process and a more uniform coverage of the fibers of this textile. They concluded that the hydrophilic character of the plasma-activated fabric leads to a higher adsorption of the water-based dispersion that contain the fluorocarbon resin and limit the de-wetting phenomenon of the fibers during the drying step. All these results highlight the importance of the plasma activation step to enhance the hydro- and the oleo-repellent properties of the modified fabrics, as assessed by different analyses (water contact angle, standard tests for hydro- and oleo-repellence, and water adsorption isotherms) [43].

Textile industry wastewater has large amounts of organic dyes that are resistant to the biological methods. Moreover, other physical and chemical processes such as adsorption and coagulation merely transfer contaminants to a secondary phase and require more treatment. Fenton and sonication processes are simple and efficient methods that are applied for the mineralization of various contaminants from polluted water sources. The plasma-treated pyrite (PTP) nanostructures were prepared from natural pyrite (NP) utilizing argon plasma due to its sputtering and cleaning effects resulting in more active surface area by Khataee et al. in 2016. They reported that, environmentally friendly plasma modification of the NP, in situ production of H_2O_2 and OH radicals, low-leached iron concentration and repeated reusability at the milder pH are the significant benefits of the PTP utilization. The significant advantages of the stable PTP are not needed for adding of H_2O_2 , low-leached iron amount, and application at the milder pH [44].

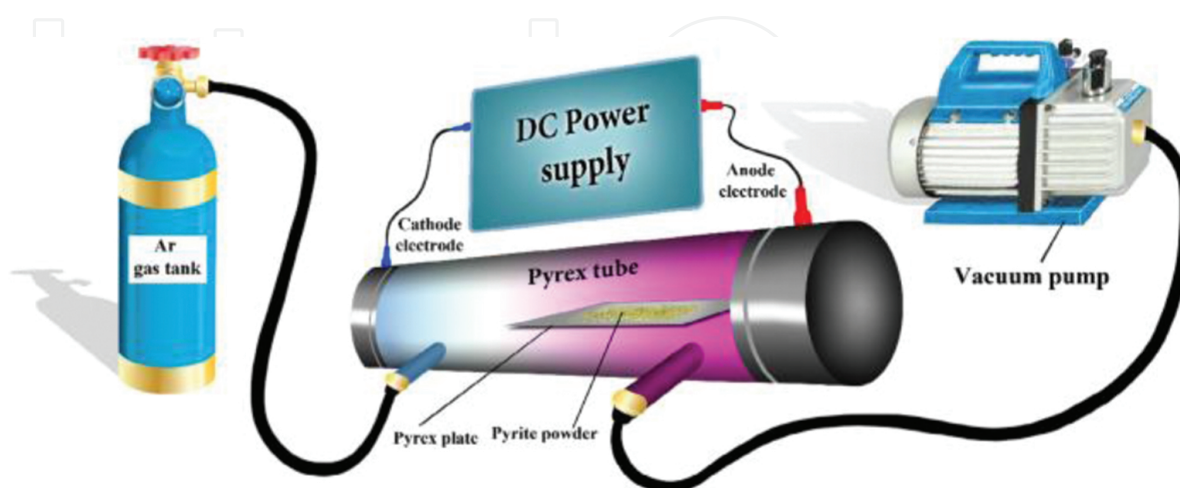


Figure 10. Schematic diagram of the glow discharge plasma system used in Khataee et al. study (2016) [44].

8. Conclusion

In textile industry, the surface modification of fibers is correlated to surface properties such as water repellence and adhesion. In the recent years, there have been many researches in developing surface modification methods to improve the surface properties of textile materials in order to develop new market products. Several surface modification methods are employed. The irradiation treatments have been ahead of recognition as a surface modification technique. Much attention has been paid to treating the surfaces of materials with irradiation methods in the past few decades. In general, treating the surface of a material with irradiation methods can cause physical and chemical changes to occur at the surface but affect the bulk properties of the material little.

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