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The Role of Plasma Technology in Surface Modification of Textiles

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In Loving Memory of Late Professor Doctor ""Mohamed Refaat Hussein Mahran""

Abstract
In order to improve the quality of the fabric, the textile industry is looking for innovative manufacturing technologies. Additionally, society needs modern environmental finishing techniques, such as the use of atmospheric pressure plasma for surface modification of textiles. These techniques include corona discharge, atmospheric pressure plasma jet (APPJ), atmospheric pressure glow discharge (APGD), and dielectric barrier discharge (DBD). These techniques are becoming more and more popular in the textile industry because they offer numerous benefits over traditional wet processing methods. Since cold plasma, also known as non-thermal plasma, may modify the polymeric surface without changing the material's bulk properties, it is thought to be superior to other common modification techniques. Air or standard industrial gases, such as hydrogen H2, nitrogen N2, and oxygen O2 at room pressure, can be used to start a plasma. Unlike chemical treatment, plasma treatment does not include the treatment of dangerous chemicals, hence there are no effluent issues. One of these physical methods used to treat thickeners and enhance their rheological characteristics is plasma treatment. After plasma therapy, active surface groups are added by plasma to give fabrics like cotton, linen, polyester, and surface fabrics qualities like antibacterial, UV, flame retardant, self-cleaning, and antistatic. This review paper gives brief information about the benefits of using plasma for various textile finishing processes by critically analysing recent research and illustrating the many kinds and mechanism of plasma technique.
Keywords: Plasma, Plasma mechanism, Surface modification, Textiles

1. Introduction

"Sustainability" is essential these days. The textile industry is also not an exception. The purpose of finishing procedures is to improve the textile product's use or aesthetic appeal. [1] The traditional method for treating textile surfaces is wet chemical processing.[2-27]

Chemical treatments provide a vast range of reagents for fabric treatment, but they also come with a number of toxic chemicals and strict process control requirements. [28] Finishing fabrics releases dangerous compounds into the atmosphere and consumes a huge amount of chemicals. [29] As such, it is important to reevaluate and enhance the selected ingredients in addition to the processing and finishing techniques. The traditional method for treating textile surfaces is wet chemical processing. Chemical procedures Even though there is a large variety of reagents available, treating cloth still calls for strict process control and a number of dangerous chemicals. [1]

The practice of changing a material's surface by physical, chemical, or biological means in order to give it unique characteristics that set it apart from untreated material is known as surface modification. Throughout time, several surface modification methodologies have been utilized to modify the surface characteristics of textiles. These methodologies may be roughly classified into four categories: physical, chemical, biological, and mechanical. Figure 1**:** [30]

In this paper we summarize the plasma technology as a physical methode used to modify the surface of textile. Plasma is a gas that no longer contains all of its electrically neutral components. [31-33]Rather, the molecules/atoms undergo ionization, i.e. [34] They acquired (or lost) one or more electrons. These unbound electrons can also be found in plasma. It should be noted that the concept of plasma is independent of the equipment used to create it, such as corona discharge, dielectrical barrier discharge, glow discharge, and so on.

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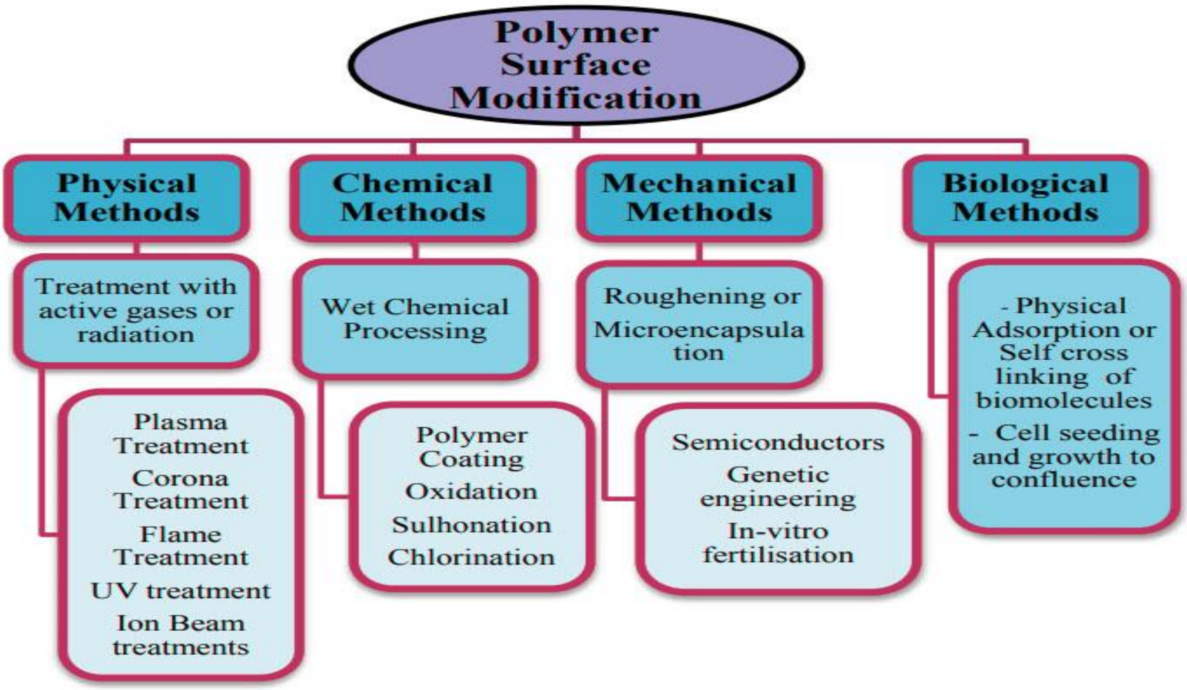

Figure 1: diagram depiction of many surface modification techniques, along with a few illustrations [30]

As a result, the word plasma is used throughout this work to refer to all of these forms of discharge. [35, 36]In practice, plasma is created by applying an electrical field to two electrodes separated by a gas.This can be done at atmospheric pressure or in a closed vessel at lower pressure. In both circumstances, the gasses utilized to form the plasma, as well as the applied electrical power and the electrodes (material, shape, size, etc.), will define the characteristics of the plasma. [35, 37] Plasma, the 4th state of matter . [37] Plasma is an ionized gas with an equal density of positive and negative charges that exists throughout an exceptionally large pressure and temperature range. Depending on the gas utilized, plasma is made up of free electrons, ions, radicals, UV-radiation, and other particles. To maintain a steady state, an electric field must be applied to the gas plasma created in a low-pressure chamber. [29, 37, 38]

Plasma techniques

Plasma, the fourth state of matter, is made up of many distinct species such as electrons, positive and negative ions, free radicals, gas atoms, and molecules in the ground or any higher state. [30] Plasma is traditionally thought to be a quasineutral species composed of an equal number of positive and negative ions, but due to long-ranged Coulomb's forces of attraction, the individual behavior of particles is lost and the entire plasma acts collectively. Plasma accounts for about 99% of all stuff in the cosmos. The temperature of natural plasma is extremely high, ranging from tens to hundreds of thousands of kelvins. [30, 39]

Advantages of Plasma Treatment

- Gas plasma technology adheres to Green technology principles by providing a clean, dry, and waste-free alternative to traditional methods. [40]
- Because most textile materials are heat sensitive, non-thermal plasma is very advantageous for textile processing. Atmospheric pressure plasma may produce surface reactions without causing significant thermal deterioration of the substrate. [41]
- - Different functional groups can be included on the fabric surface by utilizing a range of gases, depending on the type of functionality to be put on the fabric, such as wettability, adhesion, printability, hydrophobicity, and hydrophilicity. [42]
- Plasma modification is very surface-specific since it does not influence bulk characteristics and only affects the top layer.
- The produced modified layer is reasonably homogenous and covers the entire and wide surface area. [29]

Classification of Plasma

Typically, plasma can be classified as thermal (hot) and non-thermal (cold) plasma based on temperature.[30] All of the species that make up thermal plasma are in thermal equilibrium at temperatures in the millions of kelvin range. Because thermal plasma exists in the solar corona and lightning, it cannot be used to cure any substance. Non-thermal plasma, on the other hand, is kept at room temperature; while the smaller sized electrons are heated, the other bigger reactive species stay at normal temperature.[43]

Hot (Thermal) Plasmas and Their Applications

Hot plasmas, such as electrical arcs, rocket engine plasma jets, thermonuclear processes, and so on, contain an extraordinarily high energy content, causing all organic molecules to fragment to atomic levels. As a result, these plasmas can only be utilized to create extremely large amounts of caloric energy or to change thermally stable inorganic materials (metals, metal oxides, and so on). Thermal plasma is created by creating an arc discharge in a gas subjected to varying frequency electric fields. A bundle of gas ionized at extremely high temperatures has the ability to remove, fuse, or thermally alter a material. The bundle is comparable to a tool in that it is readily handled and does not come into direct contact with the treated area. Temperature, gaseous reagents, and microscopic particles injected into the plasma (plasma spraying, synthesis) or exposed to plasma in the form of 'bulk materials' (fusion and refinement in metallurgy) determine the uses of thermal plasmas. [44]

Except for the fundamental architecture of the plasma cannon (nozzle), which has not changed considerably over the previous 20 years, plasma sprayed coating has progressed dramatically. The nozzle, which consists of a cone-shaped cathode situated within a cylindrical anode that generally extends beyond the cathode, is the most important portion of the cannon. Reactive or inert gases, or mixes of them, traversing the gap between the electrodes are 'instantly' ionized, resulting in the plasma state. Powders can be injected into the plasma jet at specific positions relative to the nozzle to regulate the caloric energy absorption of the deposition materials as well as the paths of plasma-borne particles and droplets. [45]

Coating particles (powders) put into the jet are quickly melted, and the resultant droplets are deposited and cooled on the target surfaces, often resulting in tightly bonded yet porous coatings. The main benefits of employing thermal plasmas in plasma waste treatment are the quick heating rates, high processing temperatures that allow the creation of stable vitrified slugs, and low off-gas flow rates. Off-gas cleaning is a significant economic aspect in every waste processing system, and the costs decrease as gas flows increase. [46]

The main issue is the economics of the specific process, and all new developments have been directed toward improving the economics, either by combining plasma processes with conventional incinerators to take advantage of the waste's heating value, or by using waste heat to obtain a useful co-product. [47]

cold plasma

Thus, cold plasma is best suited for surface alteration of textiles since it causes minimum thermal deterioration of the fabric. Continuous energy loss occurs in non-thermal plasma, whether through radiation, conduction, or various interactions within the plasma species; thus, for continuous processing of the sample, power must be supplied continuously from an external source, typically an electrical discharge. These electrical discharges are delivered either at low pressure in vacuum chambers or at atmospheric pressure. [48]

The microelectronics and material technology industries have pioneered low-pressure plasma technologies. Low-pressure plasma systems typically operate in vacuum at pressures ranging from 1 to 100 Pa and at temperatures close to ambient. [30] Only essential plasma gases such as neon, argon, helium, nitrogen, and oxygen are then injected into the enormous vacuum chambers after the system has been pushed down. Low-pressure plasma systems have been used in textile processing, but the need for airtight enclosures makes them costly and time-consuming. As a result, the current emphasis has been on developing more accessible and simple processing techniques, which gave rise to atmospheric pressure plasma systems.[49] The atmospheric pressure plasma is created at a high pressure of around 1 atm. These systems improve low-pressure systems because they do not require the presence of vacuum conditions, and they also have more reactive chemical species with superior selectivity and a lower gas temperature. [38, 42]

Types of the Non-thermal Atmospheric Pressure Plasma System

Operating at 1 atmosphere pressure Because of their economic feasibility and ease of use, atmospheric pressure plasma sources have been developed for a wide range of research and industrial applications. [30] The following four discharges can obtain atmospheric pressure plasma discharge.

Corona Discharge

Corona discharge is the most basic form of plasma therapy. Two electrodes with opposing charges and a high voltage source are required for this type of discharge. [49] Corona discharge has an inhomogeneous electrode layout, in which one electrode is strongly curved, like a pointed needle or wire, and the other is planar or flat. The discharge occurs when current travels from the high-potential strong curvature electrode into a neutral fluid, generally air, and ionizes the surrounding region. Furthermore, the corona formed in the high field zone discharges to a lower potential area and flows through to the planar electrode. [38, 41, 50] Coronas can be either positive or negative depending on the electrode's polarity. If the curved electrode is linked to the power supply's positive terminal, it is a positive corona; if it is connected to the power supply's negative terminal, it is a negative corona. Corona treatment has a variety of commercial uses, including water purification, photocopying machines, printers, and powder coating; nevertheless, their weak and inhomogeneous character, as well as their limited area of application, have limited its use in textile processing. [41]

Atmospheric Pressure Plasma Jet

A small torch-like, non-thermal plasma generating device that uses radiofrequency (RF) power is an atmospheric pressure plasma jet (APPJ). It is made up of two electrodes, with the outer cylindrical electrode grounded and the inner center electrode pointed like a jet. These electrodes are given a gas mixture made up of helium, oxygen, argon, or other noble gases. [30, 38, 50] When RF power is applied, the plasma discharge ignites, feeding constantly on a gas mixture and producing a high-velocity stream of chemically reactive species that escapes via the nozzle after passing past the center electrode. The primary characteristics of APPJ are that it produces a steady and homogeneous discharge and does not require a dielectric cover on the electrodes. APPJ technology is utilized in a variety of applications, including sterilization of surgical and dental equipment, etching of metals and polymers, plasma-assisted chemical vapour deposition of SiO_2 and TiO_2, graffiti removal, paint removal, and many more. [51, 52]

Atmospheric Pressure Glow Discharge

A low voltage and extremely high frequency, i.e. radiofrequency, atmospheric pressure glow discharge (APGD) is created between parallel plate electrode setups separated by a few millimeters. Helium is typically utilized as the plasma-forming gas because it has a very low breakdown voltage and a longer transition time, which aids in expanding the micro-discharge sites on the insulating electrode. Because it works at a lower voltage than other atmospheric pressure discharges, the APGD is advantageous for material processing due to its capabilities for homogeneous treatment and discharge stability. Furthermore, there is no dielectric substance covering the electrodes. Because helium is expensive and difficult to recover, its practical usefulness in textile production is limited. [49, 50, 53]

Dielectric Barrier Discharge

A dielectric barrier discharge (DBD), also known as a silent discharge, occurs when at least one of two parallel electrodes is covered with an insulating dielectric barrier. These discharges function at atmospheric pressure, which is normally in the 0.1-1 atm range. A strong alternating current voltage with an amplitude of 1-100 kV and frequency ranging from a few kHz to MHz (corresponding to the lower RF—microwave band) is applied to the setup. DBDs have a dielectric layer consisting of glass, quartz, ceramic, or polymer material that is put between two metal electrodes. Depending on the processing requirements, the inter-electrode spacing ranges from a few millimeters to a few cms. [54]

When the DBD is powered with a high alternating current voltage, gases breakdown between the parallel plates in filamentary mode, resulting in a discharge composed of a large number of individual tiny breakdown filaments distributed uniformly across the entire dielectric layer, known as micro-discharges or streamers. The use of dielectric as an insulating layer has a few advantages. First, it allows for continuous current flow by avoiding the glow to arc transition, and second, it forms random streamers by electron buildup on the electrode surface to assure homogeneous treatment of any surface. [54, 55] At atmospheric pressure, the dielectric barrier discharge has become an essential technique for surface modification of textiles. Surface modification aids in the alteration of many qualities such as wettability, dye ability, stain removal, and sterilization. DBD methods are in high demand since they are a green technology that produces no effluent or hazardous chemicals. [30]

Surface Modifications Caused by Plasma Species

Once the penetration depths are established, an illustration of the textile alterations caused by gaseous plasma therapy may be shown. Obviously, inhomogeneous treatment over the whole thickness of the textile cannot be prevented, but it may be minimized by suitable treatment device design and discharge parameter selection. [56]

Electron

As illustrated in Figures 2 and 3, the electrons will cause a negative charge of the fibers on the surface (Figure 3) or even deep inside the fabric (Figure 2). All save the fastest electrons entering from the gaseous plasma will be slowed by the negative charge. As a result, the vast majority of electrons impinging on the polymer surface will have kinetic energy below the threshold for bond breakage. As a result, save for RF biasing, which is beyond the subject of this work, electrons have no impact on textile alterations. In practically all practical ircumstances, the influence of electrons on textile surface finish is negligible.

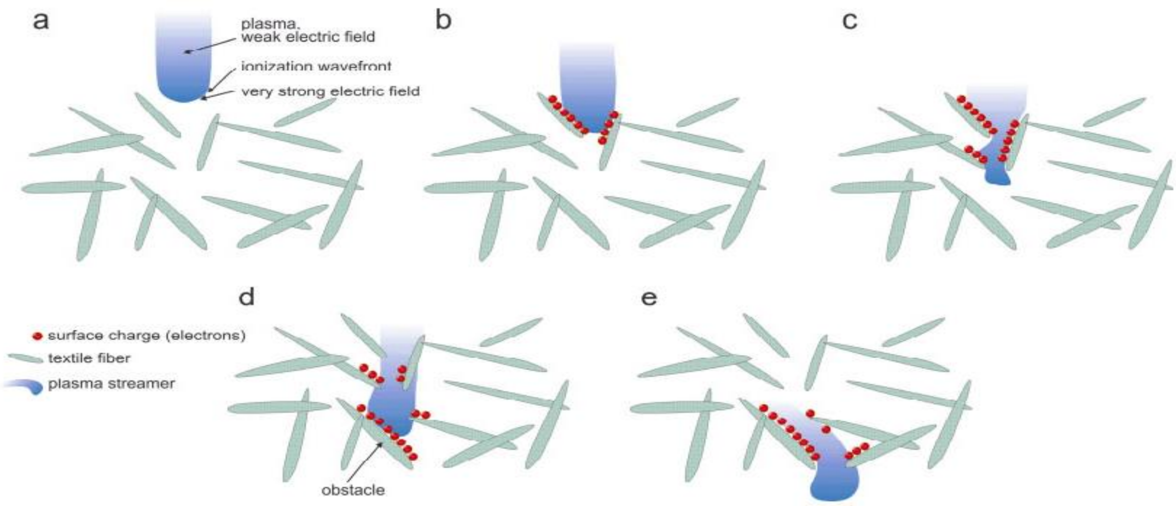

Figure 2: Illustration of a steamer penetration inside the textile and propagation through textile fibers from (a) to (e)

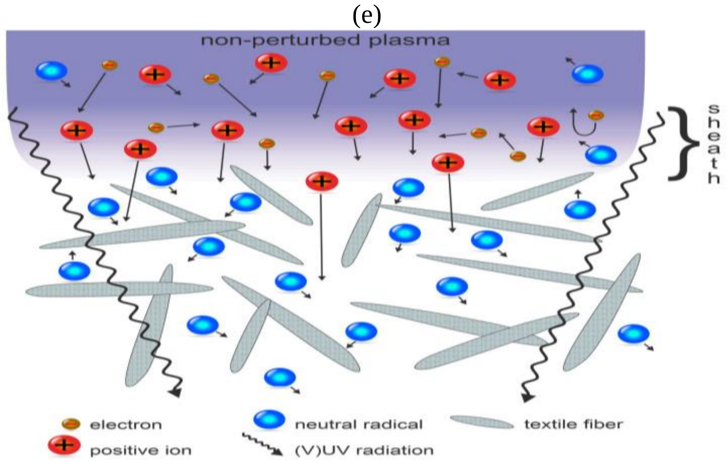

Figure 3: An illustration of the penetration path of VUV and UV radiation, charged particles, metastables, and radicals in textiles

Positively Charged Ions

If the surface charge retards negatively charged electrons, positively charged ions are propelled toward the surface, as seen in Figures 2 and 3. Because the surface of any substance exposed to plasma always has a consecutive negative charge, positively charged ions will collide with negatively charged electrons and neutralize. Surface neutralization is extremely efficient, with a near-perfect likelihood. The surplus energy (the ionization energy) will be released on the fiber surface, heating it.**[57]**

Negatively Charged Ions

Because of the adsorption of free electrons from gaseous plasma, the surfaces confronting non-equilibrium gaseous plasma are biased negatively toward the plasma, as previously stated. The negatively charged ions Will be slowed by the surface potential and steered back to the bulk plasma (important only for plasmas sustained in electronegative gases). As a result, because the negatively charged ions will not reach the fiber surface, any discussion of contact with the fibers is unnecessary.

Metastables

Electrons with sufficient energy will excite neutral molecules, atoms, and ions into electronically excited states. The excitation happens in a gaseous plasma with a high electron density and temperature. The excited states may be resonant, which means they will relax instantly (in nanoseconds) by producing a photon. Many states, however, are metastable due to quantum physics restrictions that preclude relaxing via electrical dipole radiation. Such excited states may have a long enough lifespan to allow metastables to reach the surface. The excitation energy may be transmitted to an electron bound to the polymer surface on the surface, resulting in surface modification. The impact has yet to be fully explored since very few studies on the interaction between oxygen metastables with polymer materials have been published, despite the fact that plasma scientists frequently utilize them to explain processes in oxygen plasmas.[58]

Molecular Radicals, including Atoms

When polymer materials are treated with oxygen plasma, the surface chemistry is generally governed by neutral reactive particles. [59] In practically all practical circumstances, their concentration in gaseous plasma is orders of magnitude greater than charged particle concentration. [57] The good gas phase stability is the primary cause for the high concentration of neutral reactive particles in low-pressure plasmas. A three-body collision is required for the recombination of simple radicals like atoms to parent molecules in the gas phase. At pressures below a few mbar, such collisions are rare. Atoms have a lifespan of more than a millisecond in a properly built experimental system, therefore radicals can travel many meters from the source (i.e., thick plasma). [60] In low-pressure systems, recombination occurs almost entirely on surfaces. Unlike the virtually 100% chance of neutralization of charged particles, the surface recombination of neutral radicals depends considerably on the kind of materials contacting plasma and can be as low as 0.001 for certain polymers. [61]

Plasma Technology in Textile Processing

Plasma technique has been utilized to improve the surface and bulk properties of textile materials, resulting in textile products ranging from traditional textiles to sophisticated composites. It has the potential to increase the efficiency of textile materials such as:

Wettability

There has been a lot of research on plasma treatment of various textile fibers to change their wettability qualities. Plasma treatment, for example, can increase the capacity of polyester, polypropylene, and wool to retain moisture or water droplets on their surface. Hydrophobic finishing: treating cotton fiber with a known plasma gas, such as hexamethyldisiloxane (HMDSO), results in a smooth surface with a higher water contact angle. The treatment has a considerable hydrophobization impact on treated cotton fiber.

Adhesion

Plasma technique can improve chemical coating adherence and dye affinity in textile fabrics..[29, 34]

Product quality

Due to the nature of the fiber scales, felting hand feel is an important aspect of wool garments. Traditional anti-felting has a detrimental impact on and environmental concerns. Oxygen plasma has an anti-felting impact on wool fiber without causing conventional problems.

Functionality

Various plasma gases give particular functionality to textile materials such as UV protection, antibacterial function, medicinal function, bleaching, flame retardancy, and so on. [34]

Textile characterizations for assessing plasma modification

At both high and low temp eratures, plasma can be employed. Due to the heat sensitivity of the majority of textile fibers, only low-temperature plasma (also known as cold plasma) is employed on textiles. [62, 63]

Plasma therapy can be performed using direct current (DC) or alternating current (AC) energy at low frequencies (1-500 kHz), radio-frequency (RF) (typically 13.56 or 27.12 MHz), or microwave (usually 915 MHz or 2.45 GHz). [62, 64] Plasma can be created at atmospheric pressure or at low pressure in a confined chamber. RF or microwave radiation is typically used to generate low-pressure (1-100 Pa) plasma. [65]

Although this technology produces a consistent effect and has strong repeatability in terms of textiles while using a modest quantity of gas, it is difficult to apply to large-scale continuous textile manufacturing since the sample size is restricted to the size of the closed chamber. [66, 67] As a result, the use of plasma under atmospheric circumstances is thought to be more practicable for continuous textile line manufacturing. [68]

The chemical changes in textiles caused by plasma treatment are heavily influenced by the chemical structure of the textile and the plasma gas employed. By adding new chemical groups, various plasma gases can generate various effects on the textile surface. Oxygen (O2)-containing plasma, for example, can generate new C=O or O-C-O groups on cellulosic fibers, whereas nitrogen-containing plasma can generate CN or O=C=NH groups.[69]

To create a thin hydrophobic layer on a textile substrate, fluorine-containing gases (e.g., C2F6, C3F6, and SF6) are frequently utilized. [70] Various methods, such as Fourier transform infrared spectroscopy (FTIR) and X-ray photoelectron spectroscopy (XPS), can be used to analyze changes in chemical structure. Plasma treatment of textiles influences surface energy, wettability, and color (nominal shift produced by etching, which modifies the light reflection pattern). As a result, plasma alterations on textiles are frequently evaluated by researching surface lightness, surface energy measurement, and capillary height measurement. [62, 63, 69]

Application of using plasma in finishing some fabrics

Plasma anti-static finishing processes for some textiles

The main purpose of an antistatic substance is to inhibit the formation of electricity within certain fabrics. In general, these disparities can be caused by the separation or friction of two materials, or by induction processes, such as the interaction of ionized air with an additional electron or a lack of an electron. Static electricity can be generated during production, and the textile material is also employed in transport and manipulation at the end. [71] Many textile materials include anti-static restrictions to specific relative wetness (usually range from 65 to 25 percent).

After the low-temperature plasma treatment with oxygen, the half-life decay period of the Polyester fabric was ideal. Reduced evidence that polyester's anti-static property Substance has been significantly altered. The perfect condition of plasma treatment at low temperature adequate enhancement of the anti-static property of polyester fabric computed as

(i) release power = 200 W
(ii) device pressure = 25 Pa
(iii) processing time = 3 min and Antistatic property enhancement on polyester fabric was dependent on low-temperature plasma treatment, and antistatic finishing chemical had a different antistatic mechanism. It is now understood that low-temperature plasma modification of fibers causes oxidation and deterioration (the formation of voids and pores) of the fiber surfaces. [72]

The oxidation process produces oxidized functionalities, which enhance surface energy, whereas the degradation process primarily changes the surface shape of the fibers. The number of oxygen-containing polar groups on the polyester fiber surface rises after low-temperature plasma treatment. Through hydrogen bonding, these polar groups will incorporate moisture and aid in moisture penetration and binding on the fiber surface. The water molecule can ionize these polar groups and progress to a systemic electricity conduction layer Fiber surface, which improves electrostatic material dissipation. As a result, the fiber half-life decreases following low temperature Plasma treatment. [73]

Self-cleaning

Self-cleaning has been identified as an essential trait in plants such as lotus. SEM pictures of the surface of a lotus leaf revealed a variety of micro- to nanostructures that prevent particles from adhering and roll off water droplets off the surface, scooping up long dust particles to maintain the leaf surface clean and dry even in marshy places. For such superhydrophobic self-cleaning solutions, the technological representation of this core notion has been patented under the trade name Lotus effect. [9, 11, 20, 74-83]

Because nanoparticles have a larger surface area and greater diffusibility than macroparticles, the use of crystalline TiO_2 as a photocatalyst has grown dramatically over time. Commercially, nano-TiO_2 is widely used in water purification, air purification, and disinfection, but its use in textile surface modification is still in its early phases. A variety of negatively charged functional groups such as C-O, C = O, -COH, -COOH were introduced on the fabric surface by the reaction between active O species of air and plasma-activated carbon functional groups of textiles, resulting in improved bondability of Ti^{+4} ion of TiO_2. Fabric self-cleaning feature could be improved. radiofrequency (RF) plasma (13.6 MHz, 100 W) and microwave (MW) plasma (2450 MHz, 600 W) activated cotton, polyester, and wool-polyamide. [30, 74]

Post-plasma therapy In contrast to the customary high temperature of 500 °C used for coating glass and silica, a temperature of 100 °C was adequate to attach TiO_2 to the fabric. The release of CO_2 was accompanied by the degradation of organic stains such as coffee, wine, or grease on textiles triggered by plasma and TTIP or $TiCl_4$ colloidal TiO_2. In case of cotton, a 60 min RF plasma-treated bleached cotton showed the maximum

CO_2 evolution (2000 µl) and a mercerised cotton showed the maximum amount of CO_2 for just 15 s MW plasma treatment for wine stain after 24 h suntest light irradiation. Because the MW plasma treatment was accompanied by heat, it promoted interaction between cotton tissue and the surface of TiO_2 nanoparticles, boosting dispersion rate on the fabric with minimal treatment time. In the absence of TiO_2 or any stain, no CO_2 appeared in any of the fabrics. The self-cleaning activity of pretreated polyester and wool-polyamide samples was increased in a 30 minute RF plasma-treated sample coated with colloidal TiO_2 as a basic layer, followed by additional coating of Degussa P-25 nanoparticles. [74]

The activity of nanoparticles was clearly evident, with partial discoloration caused by light and a significant amount of CO_2 gas produced. In TEM micrographs, a TiO_2 coating with thicknesses of 150-220 nm was seen for cotton samples and 20-25 nm for synthetic fabric. The XRD spectra revealed peaks for rutile TiO_2 nanoparticles as well as some amorphous TiO_2. The mechanism of self-cleaning was explained by a photochemical reaction in which coffee or wine pigments inject an electron in the TiO_2 conduction band to generate highly active O-radicals, or the excited pigment reacts with photo-induced holes, which react with carboxylic acids via a Kolbe-type reaction to generate CO_2. The active O– species further generate oxidative radicals like $HO_2^{\cdot}$–, $OH^{\cdot}$, $RO^{\cdot}$, $RO_2^{\cdot}$ which will eventually degrade the textile stains. [84]

$$e_{cb}^- + O_2 \longrightarrow O_2^- \tag{1}$$

$$RCOO^- + h_{vb^+} \longrightarrow R^\bullet + CO_2 \tag{2}$$

Flame Retardant

The effects of low temperature plasma pretreatment on metal salt absorption by cotton textiles as well as the flame retardant qualities of the treated samples before and after dyeing were studied. As metallic salts, titanium dioxide (TiO2), zinc sulfate (ZnSO4), lead(II) acetate (Pb(C2H3O2)2, aluminum sulfate (Al2(SO4)3), and silver nitrate (AgNO3) were added to cotton textiles. Some analyses, such as char yield and LOI, have been conducted in order to assess the flame retardant properties of treated materials. The higher the char production, the higher the LOI values of the plasma pretreated/metal salt loaded textiles. According to the findings, the injected plasma pretreated cotton textiles show good flame retardant qualities. The LOI value increases from 18.6 to 23.3 when inoculated in a 0.01 M solution of Silver Nitrate (AgNO3). According to the findings, the FR property of treated textiles can endure after dyeing, and dying the infected cotton fabrics has no detrimental influence on the flame retardancy of cotton fabric. [85-87]

Cotton textiles benefit from the use of nanoclay as a flame retardant. Cotton textiles were treated with low temperature plasma to boost their adsorption capability in another study. Nanoclay was utilized as a flame-retardant finishing product for cotton textiles after plasma treatments. The char yield of the untreated sample before treatment was 1.9%, however it rose significantly for the treated samples. The char production of the nanoclay-treated sample is 10.20%, which is 5 times higher than the untreated sample. Furthermore, the results suggest that N2 plasma treatment increases the flame retardant capabilities of the cotton sample. It is observed that, Nitrogen plasma has synergistic effect on nanocaly for flame retardant properties. Char yield value for N2 plasma/nanoclay treated cotton increase to 12 %. Also the same results for LOI values have been achieved. [74] The LOI values can be increased by plasma pretreatment and nanoclay exhaustion up to 23.5%. The quicker disintegration of nanoclay to promote char formation, which might block the passage of heat, energy, and O2 between flame and cotton materials, is linked to the improved flame retardancy of the treated samples. The presence of nanoclay causes the establishment of a barrier layer, which inhibits the propagation of fire inside the material while increasing the rate of flame spread beyond the specimen's surface. During the vertical burning test, the treated cotton materials had a shorter afterglow period and no after-flame.[88]

Antibacterial Finishing

Cotton is a great natural material, however it is susceptible to bacterial growth. Cotton, being a hydrophilic fabric material, easily provides favorable circumstances for the growth of microorganisms, such as humidity, sufficient temperature, and nourishment. This can cause an unpleasant odor, stains, and discoloration in the fabric to some extent. As a result, cotton materials must be treated with an antibacterial treatment. Furthermore, the perfect antibacterial finishing should be non-toxic, washable, eco-friendly, and long-lasting. [7, 19, 29, 77, 80, 89-95]

Antibacterial function and resilience of different cellulosic substrates are significantly improved. Cotton, linen, viscose, and lyocell were pre-surface modified with N2 or O2 plasma to provide antibacterial characteristics. new active and binding sites, NH2 groups, and the consequent fabric surface change Packing of biosynthesized silver nanoparticles (AgNPs) in combination with specific antibiotics. the Ag-content, as well as a significant improvement in the treated material's antibacterial efficacy. The improvement of the aforementioned properties reflects the positive impact O2-plasma pre-treatment had on surface modification and activation of the treated substrates using the exhaustion method, which can be discussed in terms of surface morphology, cellulose content, amorphous/ crystalline areas, fabric weight, and extent of surface changing and functionalization, which in turn affected the extent of Ag NPs retention and antibacterial efficacy.[28, 30]

The significant increase in antibacterial activity of plasma-treated, AgNPs-loaded fabric samples, even after 15 washing cycles, is a direct result of better AgNP bonding via plasma-generated polar groups, i.e. -COOH groups.

The remarkable decrease in antibacterial activity of Ag-NP treated fabric samples that were not plasma pre-treated can be attributed to physically adhered Ag-NPs onto the fabric structure, resulting in less fixation and easier removability when compared to plasma treated samples. [39]

The surface of cellulose substrates was pretreated with O2 plasma before the plasma polymerization process, which used acrylic acid (AAc) as a monomer. After treatment with AAc, the surface of the cotton fibers was cleaner and smoother, with micro-fibrils visible along the fiber axis. [63]

The variables in argon plasma treatment were used to investigate the influence of polyester fabric on comfort and antibacterial characteristics. In terms of In terms of water vapor permeability, coagulability, and antibacterial activity, plasma-treated polyester materials outperformed untreated fiber. Using the program Design-Expert, the best operational power values were 600 W, 30 S treatment duration, and 2.8 mm electrode spacing. [53] The intensity of the treatment affects the process's efficiency; the intensity of corona discharge at atmospheric pressure (CDAP) is a function of dischrge power and exposure durations. [74]

Conclusion and Future Trend

The technique for treating fabrics with gas plasmas is still in its early stages. Plasma, the fourth state of matter, was initially hypothesized by I. Langmuir in 1926 and is presently being effectively studied in a variety of sectors. Textiles can be treated with plasma using either atmospheric or low-pressure equipment. The impact of plasma therapy on textiles relies on flow rate. Selecting the right plasma settings can improve fiber wettability, surface roughness, functionality, and dyeability. cold plasma is best suited for surface alteration of textiles since it causes minimum thermal deterioration of the fabric. Low-pressure plasma systems typically operate in vacuum at pressures ranging from 1 to 100 Pa and at temperatures close to ambient. It offers various benefits over typical textile processing technologies. Plasma therapy can be performed using direct current (DC) or alternating current (AC) energy at low frequencies (1-500 kHz), radio-frequency (RF) (typically 13.56 or 27.12 MHz), or microwave (usually 915 MHz or 2.45 GHz). RF or microwave radiation is typically used to generate low-pressure (1-100 Pa) plasma. Plasma technology offers an ecologically benign and adaptable method of improving the surface and bulk characteristics of textile materials. This method may be used in a variety of aspects of textile processing, including pretreatment, dyeing, and finishing. Pretreatment, coloring, and finishing are all steps in the process. Plasma technology may be used to remove PVA sizing material from cotton fibers, to give wool anti-felting properties, and to improve the dyeability of natural and synthetic fiber fabrics. This technique may be used to create unique functional fabrics. Thus, although being a pricey technology at first, it enables higher production rates, lower production costs, better goods, and, most significantly, finishes on textiles that are either impossible to acquire or not obtained at all using other technologies. Above all, Plasma technology eliminates the environmental issues that older technologies face.

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