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Enhancing the properties of Textile Fabric using Plasma Technology

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

Abstract
Technology for plasma treatment is thought to be a useful tool for enhancing the qualities of textiles and fabrics, particularly polyamide. The fabric's capacity to absorb dyes and inks, as well as its dyeability and printability, can all be enhanced by applying different plasma treatment methods. The fabric's tensile strength, flexibility, and resistance to corrosion and damage can all be improved. Thus, polyamide fabric's qualities can be enhanced and elevated through the use of plasma treatment technology, rendering it a superior option for a range of applications.
Keywords: plasma treatment, Thermal plasmas , non thermal plasmas..

1. Introduction

Textile fibres are typically modified in a number of ways to improve their comfort, functionality, and look [1] . Chemical, physical, biological, mechanical, and combinations of these alterations were used. [2-8].

Large volumes of water are used in the majority of commercially used wet processing techniques for textile fibres. These very water-intensive textile wet processes include dying, bleaching, and scouring, among others. In addition, a lot of chemicals are typically used in the dyeing and finishing of textiles, which contributes to pollutants in the effluent that is released. [9].One viable option for environmentally friendly waterless surface modification of textile substrates would be plasma irradiation. [10-13]

2. Plasma treatment

plasma is a partly ionised gas .Sometimes called the fourth state of matter. [10, 11, 13-17].

It is a collection of charged atomic particles that move randomly and have a high enough particle density to maintain their average electrical neutrality. Positive ions, electrons, neutral gas atoms or molecules, ultraviolet light, and excited gas atoms or molecules—which have the capacity to hold a significant amount of internal energy—are all found in plasma. Any surface that comes into contact with the plasma can and will interact with any of these organisms. The effects of the plasma can be exactly tailored or specified onto the surface by selecting the gas mixture, power, pressure, etc. The three states of matter that are most familiar are solid, liquid, and gas. Energy can be added or removed to change between the states (e.g., heating/cooling). . **[18]**.

For good reason, plasmas are so frequently referred to as the fourth state of matter (Figure 1).

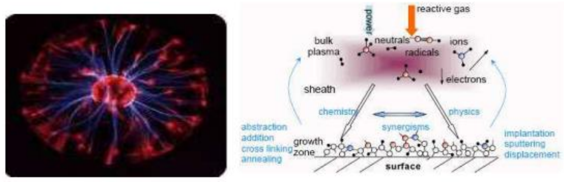

Figure-1: (a) condensed plasma, (b) plasmas are a mixture of reactive species. [18]

2.1. Physical Processes in Plasma:

The change of state serves as the fundamental physics of plasma technology. Energy-fed matter transitions from a solid to a liquid and then back to a gaseous state. Ionisation, or the release of electrons from atoms or mSolecules into the plasma state, happens when energy is applied to the gaseous substance. Within the region of 0.1–10 eV, the electrons in the plasma gain energy. In the range of 0.025 eV, the ions and molecules attain energy without exhibiting thermodynamic equilibrium,

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which is necessary for the disintegration of neutral ions and molecules. **[19]**.

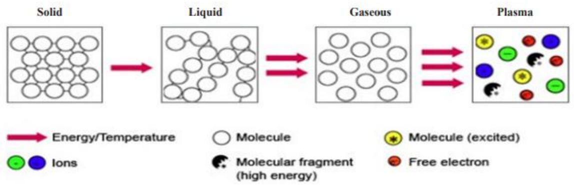

Figure 2: State of substance in [20]

2.2. Different Types of Plasma

It is challenging to categorise plasma in a way that is universal due to its vast variety. However, dividing plasma into two categories—thermal and non-thermal—is the first straightforward and impartial method of classifying various types of plasma. **[21]**.

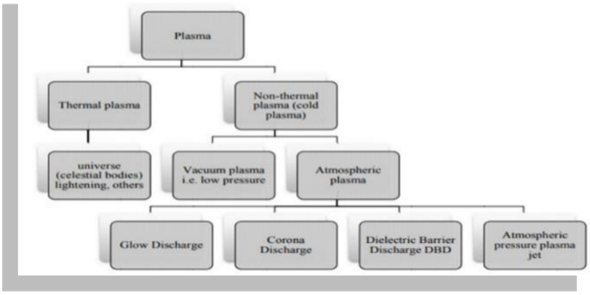

Fig. 3: Two basic types of plasma are used in industrial plasma technology [20]

2.2.1. Thermal plasmas

Numerous techniques, including electrical discharges (free burning, plasma torches), RF (Resonance Frequency), laser, and microwave discharges at near-atmospheric pressure, can also be used to intentionally create thermal plasmas. **[22]**. Thermal plasmas are defined by extremely high temperatures (thousands of degrees Celsius) and the state of thermal equilibrium that exists between all the various species present in the gas. It is possible to witness thermal plasma in the northern lights, stars, and other celestial bodies.

2.2.2. Non-thermal plasmas

Non-thermal plasmas are ones in which the electrons and higher mass particles—neutral atoms or molecules, ions, and fragments of neutral molecules—do not achieve thermodynamic equilibrium, not even locally. The temperature of the electrons in this kind of plasma is substantially higher than the temperature of the other particles. While the temperature of the gas stays close to room temperature, the electrons can reach temperatures of 104–105 °K (1–10 eV). **[23]**.

Since the majority of textile materials are heat-sensitive polymers, non-thermal plasmas, also known as cold plasmas, are especially well suited for processing and surface modification of textile materials. Such discharges have been found to have the primary benefit of significantly altering the surface's chemistry and morphology, which increases hydrophilicity and increases fibres' susceptibility to various chemical species without changing the bulk properties of the materials. **[24]**.

2.2.3. Classifications of Non-Thermal Plasma

There are two types of cold plasmas: atmospheric pressure plasmas and vacuum or low pressure plasmas. The processing speed, sample size, and anticipated modification extent determine which process should be used. **[25]**. Vacuum plasma is frequently used to etch, polymerize, or create free radicals on the surface of textile substrates in order to accomplish a variety of effects. **[26]**.

However, the technology of low-pressure plasma (LPP) requires costly vacuum systems, which poses challenges for scaling up and achieving continuous processing. The technique's commercial viability in the textile industry has been severely curtailed by these problems. [27].

Since atmospheric plasmas don't require pricey vacuum equipment and enable continuous, uniform surface processing, they offer a more affordable option to low-pressure plasma and wet chemical treatments. [28].

The four primary atmospheric plasma types that are used on textiles are as follows:

2.2.3.1. Dielectric barrier discharges (DBDs):

Dielectric discharges occur when two electrodes are covered with a dielectric substance, with a thickness varying from a few mm to a µm, in order to restrict the discharge current. A DBD electrode's spacing from another electrode can range from micrometres to centimetres, depending on the voltage applied and the gas combination being employed. Manifold symmetry is one of the benefits of DBD discharges, and as such, these discharges have applications in large-area surface alteration. Typically, DBD discharges are run at an electrode voltage of a few thousand volts and a frequency range of a few hertz (AC) to megahertz (RF). **[29, 30]**.

2.2.3.2. Atmospheric pressure plasma jets and plasma torches:

Even while it's far gentler than a plasma torch, this room-temperature technique is nevertheless rather effective. Compared to DBD, plasma jet has the benefit of producing uniform reactive gases and being able to be applied to the surface of any shape object. APPJ can only be used to treat the side of the treated material that faces the plasma jet. **[31]**.

2.2.3.3. Corona discharge

The earliest plasma technology used to modify polymer surfaces is called Corona. A corona discharge is created at atmospheric pressure by connecting two electrodes of different sizes and shapes with a high voltage (10–15 kV) at a low frequency. Extremely narrow interelectrode spacing is necessary because the discharge energy density drastically drops as the distance between the electrodes decreases. (~1 mm), which makes thick materials and quick, reliable treatments incompatible. Although corona treatment may increase the surface area and surface roughness of fibres, its non-uniform ionisation largely affects loose strands and does not penetrate deeply into fabrics, making it an uneven treatment for textiles. **[32]**.

2.2.3.4. Atmospheric pressure glow discharge (APGD)

is produced with a greater frequency and lower voltage than DBD plasma. Its characteristics include uniformity, a prolonged duration, and low-to-moderate area power densities that prevent surface damage or heating. Two parallel electrodes that are spaced a few millimetres apart are connected to a radiofrequency source. To keep a DC glow discharge going, the electrodes need to be conductive. In the simplest scenario, a potential between electrodes placed inside a cell holding a gas—typically argon or helium—at atmospheric pressure—between a few kV and 100V—is applied to induce a discharge. **[33]**.

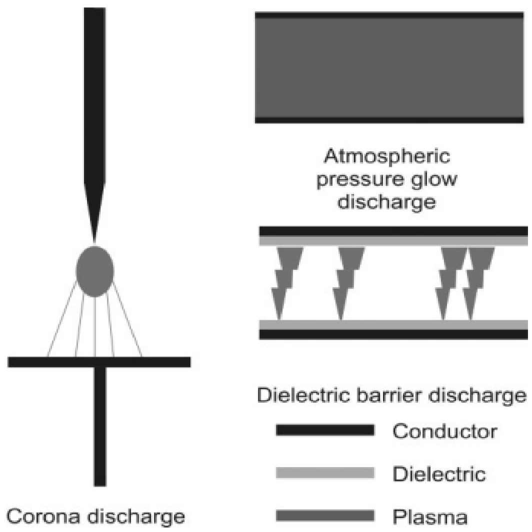

Figure 4: Plasma types utilized for textile treatment: dielectric barrier discharge, atmospheric pressure glow discharge, and corona [34]

2.3. Application of Atmospheric Pressure Plasma in Textiles

Owing to the benefits of atmospheric pressure plasma, a thorough investigation into its application on textile materials has been conducted. Textile materials modified with plasma exhibit improved wettability by either increasing hydrophobicity by removing hydrophilic functional groups or converting hydrophilic groups into non-hydrophilic ones, or by enhancing hydrophilicity by inserting the -C=O, -C-O, -COOH, -OH, and -NH2 groups. Additionally, by increasing the dyeing rate, the hydrophilic layer removal enhances dyeability. **[35]**.

2.4. The effect of plasma treatment on textile substrates:

On textile substrates, plasma modification is achieved through the physicochemical interaction of reactive species, primarily categorised as ablation and polymer formation, with the substrate.

Factors such as energy density, feeding gas, and discharge power level affect the dominance of polymer production throughout the plasma treatment process. Furthermore, there is a significant correlation between the plasma alteration mechanisms and the type of feeding gas. In contrast to hydrogen, which is reductive in nature, oxygen is oxidative. Film deposition, which alters the polymer surface directly, is favoured by polymerizing gases with high carbon and hydrogen atom proportions, such as ethanol, ethylene, and methane. However, by oxidation, ablation, and cross-linking, non-polymerizing gases such noble gases, nitrogen, oxygen, hydrogen, and ammonia alter the surfaces of polymers. **[35]**.

2.5. Plasma's effect on a material's surface:

A variety of plasma particles, including electrons, ions, radicals, and neutrals, as well as UV photons of varying energies that strike the surface, attack a material when it is subjected to a plasma beam. A portion of these active species possess sufficient energy to initiate chemical bond breaks and initiate reactions on the surface of the fibre. **[36]**. The type of textile substrate and the working gas have an impact on the changes that arise. Among the gases or gas mixtures utilised for the plasma treatment of textiles are oxygen, air, argon, helium, carbon dioxide, nitrogen, hydrogen, tetrafluoromethane, water vapour, methane, or ammonia. **[37, 38]**.

The four bases—surface cleaning, etching, surface activation, and polymerization—basically rely on the parameters of the plasma treatment.

2.5.1. Surface cleaning

The process of eliminating contaminants and impurities, such as oils, greases, and oxides, from the substrate surface is known as surface cleaning. During plasma cleaning, contaminants are volatized and removed, but the bulk properties of the substrate remain unchanged. **[39]**.

2.5.2. Surface etching

The process of physically removing surface material from a substrate that has been treated and creating volatile compounds at the surface through chemical reactions is called plasma etching. In surface etching, inert gases (such as argon, helium, etc.), nitrogen, or oxygen plasmas are frequently employed. The kind of substrate, power, gas flow, substrate position, and other operating conditions all have an impact on the etching rate. **[40]**

2.5.3. Surface activation

The process of adding new functional groups to a treated substrate in order to modify its surface energy and confer new characteristics is known as surface activation. In gases that don't polymerize, plasma activation happens. On the treated material, the reactive plasma species that makes contact with the surface breaks covalent bonds and releases free radicals. Surface radicals react with active plasma species to form carboxyl, hydroxyl, carbonyl, and amino groups, as well as other active chemical functional groups on the substrate surface (figure 5). This activation modifies the surface's characteristics and chemical activity. For instance, the grafting of hydrophilic and polar functions by oxygen plasma increases the surface energy of the material. **[41]**.

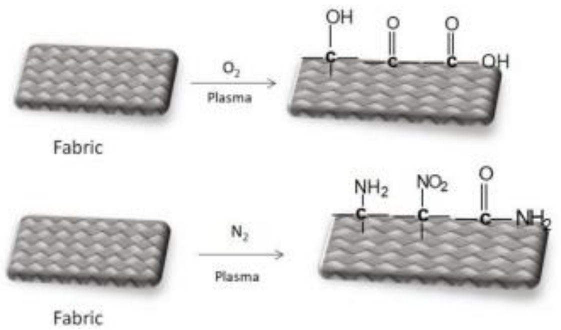

Figure 5: Creation of functional groups in plasmairradiated textile fabric. [41]

2.5.4. Polymerization

In order to create a thin polymer coating on the substrate surface, plasma polymerization entails the polymerization of an organic monomer, such as tetrafluoroethylene (C2F4) or hexafluoropropylene (C3F6). The process starts with plasma irradiation of the surface, which creates reactive bonding sites and activates the surface in preparation for coating. The plasma deposits and grafts molecular fragments to the surface during the polymerization process. **[42]**

3. Applications of plasma in textile industry:

The textile industry uses plasma treatments for a number of reasons, such as surface energy modification, surface topography modification, surface cleaning, adhesion improvement, and hydrophilicity enhancement.

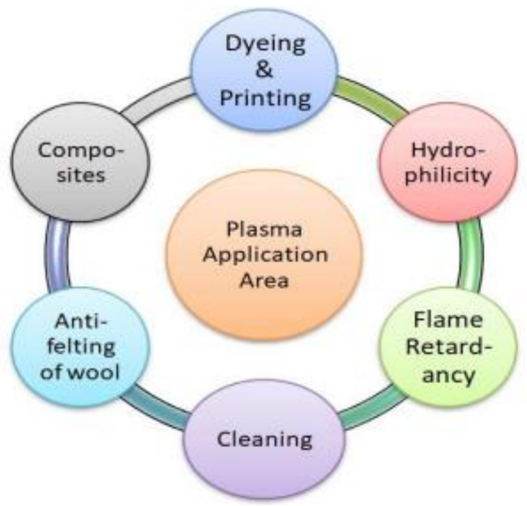

Figure 6: The different applications of plasma on textiles. [40]

3.1.1. Improve the mechanical qualities

cotton and other cellulose-based polymers are made softer by applying an oxygen plasma treatment. decreased felting of wool after oxygen plasma therapy. **[18]**

3.1.2. Wetting

Improvement of surface wetting in air-, NH3-, and O2-treated synthetic polymers (PA, PE, PP, and PET PTFE).The hydrophilic treatment also functions as an antistatic and dirt-repellent finish.

3.1.3. Dyeing and printing

Capillarity in cotton and wool is improved after being treated with oxygen plasma. enhanced polyamide and polyester dyeing with Ar- and SiCl4-plasma, respectively. **[18]**

3.1.4. Improving hydrophilic properties:

It has been demonstrated that plasma treatment improves the hydrophilic properties and surface energy of textile substrates. The creation of polar functional groups on the fabric surfaces during plasma or during post-plasma reactions is the main cause of the variations in surface energy. However, because textile materials have a diverse structure, wetting time and other indirect approaches are typically used to evaluate how wettable plasma-treated surfaces are. **[43]**.

Figure 7 illustrates how hydrophobic and plasma-treated hydrophilic surfaces behave with respect to water vapour. The former are unable to create hydrogen bonds with water vapour molecules, whilst the latter are able to do so by the use of any polar groups, including amino, carboxyl, and hydroxyl groups.

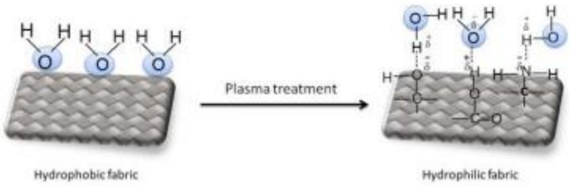

Figure 7: Hydrophilicity of plasma-treated fabrics. [43]

3.2. Plasma treatment of natural fibres

Cotton, wool, and silk are examples of natural fibres that have a variety of qualities that satisfy consumer desire.

Cotton: Activation, hydrophilic, hydrophobic, and other surface alterations are among the gas plasma's potentialities.

After being exposed to oxygen plasma, cotton's specific surface area increases. Conversely, the application of hexamethyldisiloxane (HMDSO) plasma results in a smooth surface that increases the water's contact angle to a maximum of 130° C. As a result, hydrophobization has a powerful effect. Similarly, the surface chemistry of the fibres clearly shows the presence of fluorine when hexafluoroethane plasma is employed in place of HMDSO plasma, and the material becomes extremely hydrophobic. Nevertheless, the hydrophobization has no effect on the transfer of water vapour. An effect called the Lotus effect is produced when hydrophobization and enhanced specific surface area work together to make it easier for water droplets to lift dirt particles off the surface. Applying intense oxygen plasma treatments to cotton fabric can potentially have unfavourable results, such as decreased resistance to tearing and abrasion. **[18]**.

3.2.1. Plasma treatment of wool fibres

Wool has a very complicated morphology that goes beyond the fibre stem to the surface. A directional frictional coefficient is produced by the overlap of cuticle cells. Furthermore, the surface itself has a high hydrophobicity. Consequently, fibres clump in an aqueous solution due to the hydrophobic effect and only travel to their root end when subjected to mechanical activity. This is the cause of shrinking and felting. Wool treated with plasma has two surface effects. First, the hydrophobic lipid layer on the surface is partially lost and oxidized; this affects both the covalently bonded 18-methyl-eicosanoic acid and the adhering external lipids. Exocuticle: The layer beneath the epicuticle (the fatty acid layer at the very surface) is strongly disulfide- cross linked. **[44]**

3.2.2. Plasma treatment of synthetic fibres

Synthetic fibre surface modification is thought to be one of the greatest ways to achieve contemporary textile finishing techniques for a variety of uses. **[45]**. The most often used polymers in the textile industry are synthetic fibres, specifically polyethylene terephthalate (PET), polyamide (PA), polyacrylonitrile (PAN), and polypropylene (PP). These fibres' diverse performance features allow them to outperform natural fibres in terms of production, with a 54.4% market share. In addition to their advantageous qualities, they have a number of drawbacks, including hydrophobicity, poor dyeability, poorer comfort when wearing, accumulation of electrostatic charges, finishing issues, and inadequate washability because of their hydrophobic nature.

It was discovered that applying an atmospheric plasma treatment might oxidize the surfaces of synthetic fibres. Following treatment with plasma treatments of synthetic polymers, the water contact angle on these surfaces dropped: on non-woven polypropylene (PP) films, it dropped from 110° to 42°; on polyethylene (PE) films, it dropped from 105° to 50°; and on PET films, it dropped from 90° to 15°.[46].

Fluorocarbon plasma treatments can also be used to create hydrophobic surfaces. Vacuum plasmas are used instead of atmospheric pressure for these therapies. [47]

4. Summary

Textile technology will inevitably involve plasma technology, with all of its potential and difficulties. With plasma technology, there are countless and limitless possibilities. Textiles using plasma technology are starting to00 develop quite quickly. The extent to which technology will change our lives will only be determined by human ingenuity. It is accurate to state that plasma technology is advancing the industrial revolution gradually but steadily.

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6. Conflict of interest

The authors have no conflict of interest

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