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Application of Plasma Technology in Textile processing

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Abstract :- *Textile materials have inherent characteristics that make them very precious, supple, lightweight, strong, large surface to volume ratio, good touch, gentleness, etc. Due to this, they are outstanding for imparting additional functionalities like hydrophobic or antibacterial. Conventional wet methods for applying such finishes require the use of large amounts of chemicals, soft water and energy in form of manpower and electrical energy. Plasma is a dry processing method and provides a solution to reduce the use of all mentioned property. In this overview, a discussion on how plasma can attain on textile materials and what the current state of addition in textile processing has presented.*

Keywords: *Plasma, Plasma treatment, Textiles etc*

Introduction

Plasma technology

Plasma is the 4th state of matter and a gas becomes plasma when the kinetic energy of the gas particles rises to equal the ionization energy of the gas. When this level is reached, collisions of the gas particles cause a rapid cascading ionization, resulting in plasma .When the neutral molecules of a gas are energized, e.g. by exposing to high electric field, to a point when some electrons become free and the gas turns into a mixture of electrons, ionized atoms and molecules, photons and residual neutral species. In this state it behaves as a chemically very active environment and there is a high likelihood of surface interaction with organic substrates. It is also possible to genetate plasma at room temperature. [1,2].

Different forms of plasma

Artificially produced plasma	Terrestrial plasmas	Space & astrophysical plasmas
• Those found in plasma display. • Inside fluorescent lamps, neon signs etc. • Rocket exhaust. • The area in front of space craft's heat shield during reentry into the atmosphere. • Fusion energy research. • The electric arc in an arc lamp, an arc welder or plasma torch. • Plasma used for surface modification of textiles etc.[2,3]	• Lighting. • Ball lighting. • St. Elmo's fire. • Sprites, elves, jets. • The ionosphere. • The polar aurora.[2,3]	• The sun and other stars • (Which are plasmas heated by nuclear fusion). • The solar wind. • The interplanetary med (Space between the planet) • The Io-Jupiter flux-tube. • Accretion discs. • Interstellar nebulae.[2,3]

Table no 1 Forms of plasma

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Plasma background

Basics and with material processing what is plasma ?

Irving Langmuir first used the term plasma in 1926 to describe the inner region of an electrical discharge. Later, the definition was broadened to define a state of matter in which a significant number of atom and/or molecules are electrically charged or ionised. The components present will include ions, free electrons, photons, neutral atoms and molecules in ground and excited states and there is a high likelihood of surface interaction with organic substrates. In order to maintain a steady state, it is necessary to apply an electric field to the gas plasma, which is generated in a chamber at low pressure.

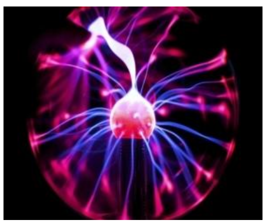

Fig no 1 Condensed plasma[3]

A plasma is a gas of which a fraction of its constituents are no longer electrically neutral. Instead, the atoms/ molecules are ionized, i.e. they lost (or gained) one or more electrons. These free electrons are also present in the plasma. Note that the definition of plasma is not dependent on the equipment needed to generate it, e.g. corona discharge, dielectrically barrier discharge, glow discharge, etc. Consequently, the term plasma is used in this text to represent all these types of discharge. Practically, one generates the plasma by applying an electrical field over two electrodes with a gas in between. This can be carried out at atmospheric pressure or in a closed vessel under reduced pressure. In both cases, the properties of the plasma will be determined by the gasses used to generate the plasma, as well as by the applied electrical power and the electrodes (material, geometry, size, etc.).[3,4,5]

Although the fraction of charged particles in a plasma is typically very low (order of 1% or below), they are Crucial as they can be given energy via an electrical field. For materials processing, the aim is to make physicochemical reactions happen. These reactions will only take place if a certain energy barrier can be overcome. Traditionally, this is carried out by heating the material (adding thermal energy). This is a very inefficient process because all particles become energized, whereas only a fraction of them is needed for the reaction. In plasma, energizing only a limited group of the particles to enable physicochemical reactions is possible because of the interaction of charged particles with the applied electric field. This explains why materials processing via plasma can be very efficient. To illustrate that this is not only theoretical, the author refers to an LCA study about imparting oleo phobic properties on a PET substrate.1 This study shows that only about one-third of the energy is needed for obtaining this property via a plasma process as compared to traditional wet processing. Moreover, the LCA study shows that also the environmental impact of the plasma process is considerably smaller (at least a factor of two) for what concerns the contribution to CO_2 emission, the acidification, the photochemical ozone creation potential and the eutrophication. [3,4,5]

Principle of plasma processing

Plasma technology is a surface-sensitive method that allows selective modification in the nano-meter range. By introducing energy into a gas, quasi-neutral plasma can be generated consisting of neutral particles, electrically charged particles and highly reactive radicals. If a textile to be functionalized is placed in a reaction chamber with any gas and the plasma is then ignited, the generated particles interact with the surface of the textile. In this way the surface is specifically structured, chemically functionalized or even coated with nm-thin film depending on the type of gas and control of the process.

The plasma atmosphere consists of free electrons, radicals, ions, UV-radiation and a lot of different excited particles in dependence of the used gas. Different reactive species in the plasma chamber interact with the substrate surface. Cleaning, modification or coating occurs dependent of the used parameter.

Plasma treatments have been used to induce both surface modifications and bulk property enhancements of textile materials, resulting in improvements to textile products ranging from conventional fabrics to advanced composites. These treatments have been shown to enhance dyeing rates of polymers, to improve colourfastness and wash resistance of fabrics, to increase adhesion of coatings, and to modify the wet-ability of fibres and fabrics. Research has shown that improvements in toughness, tenacity, and shrink resistance can be achieved by

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subjecting various thermoplastic fibres to a plasma atmosphere. Recently, plasma treatments have produced increased moisture absorption in fibres, altered degradation rates of biomedical materials (such as sutures), and deposition of low friction coatings.

Unlike wet processes, which penetrate deep into the fibres, plasma produces no more than a surface reaction, the properties it gives the material being limited to a surface layer of around 100 angstroms. These properties are very varied and can be applied to both natural fibres and polymers, as well as to non-woven fabrics, without having any effect on their internal structures. For example, plasma processing makes it possible to impart hydrophilic or hydrophobic properties to the surface of a textile, or reduce its inflammability. And while it is difficult to dye synthetic fabrics, the use of reactive polar functions results in improved pigment fixation. Also, with plasma containing fluorine, which is used mainly to treat textiles for medical use, it is possible to optimize biocompatibility and haemocompatibility - essential for medical implants containing textiles.

Plasma technology in textile

Various plasma technologies used in textile There are many different ways to induce the ionisation of gases. (1) Glow discharge, (2) Corona discharge, (3) Dielectric Barrier discharge, (4) Atmospheric pressure plasma technique.

a) Glow Discharge:

It is the oldest type of plasma technique. It is produced at reduced pressure (low-pressure plasma technique) and provides the highest possible uniformity and flexibility of any plasma treatment. The plasma is formed by applying a DC, low frequency (50 Hz) or radio frequency (40 kHz, 13.56 MHz) voltage over a pair or a series of electrodes. (Figure A, B, C) Alternatively, a vacuum glow discharge can be made by using microwave (GHz) power supply. [3,6-9]

b)**Corona Discharge:**

It is formed at atmospheric pressure by applying a low frequency or pulsed high voltage over an electrode pair, the configuration of which can be one of many types. Typically, both electrodes have a large difference in size (Figure shown below). The corona consists of a series of small lightning-type discharges; their in homogeneity and the high local energy levels make the classical corona treatment of textiles problematic in many cases. [3,7,8]

c) Dielectric-Barrier Discharge:

DBD is formed by applying a pulsed voltage over an electrode pair of which at least one is covered by a dielectric material (Figure shown below). Though also here lightning-type discharges are created, a major advantage over corona discharges is the improved textile treatment uniformity.

d) Atmospheric pressure plasma technique:

As discussed earlier, there are various forms of plasma depending on the range of temperature and electron density. Generally, high plasma densities are desirable, because electrons impact gas molecules and create the excited-state species used for textile treatment. Having more electrons generally equates to faster treatment time. However, very high plasma densities (greater than 1013 electrons cm-3) can only exist with very high gas temperature (Thermal Plasma). This extremely high level of plasma density is unsuitable for textile treatment, because the plasma's energy will burn almost any material. Hence for textile processing, the plasma needs to do their job at room temperature, thus the name 'cold plasma'.[3,7]

This is due to the fact that the energy of the plasma is mainly confined to the energy of low mass electrons. Non-thermal plasma or cold plasma is characterized by a large difference in the temperature of the electrons relative to the ions and neutrals. Thus, Te >> Ti ˜ Tn. As the electrons are extremely light, they move quickly and have almost no heat capacity. Ionisation is maintained by the impact of electrons with neutral species. These plasmas are maintained by passing electrical current through a gas. The low temperature makes them suitable for textile processing. However, non-thermal plasmas generally require low-pressure or vacuum conditions.[3,8,9]

Despite all the significant benefits, plasma processing has failed to make an impact in the textile sector because of a particular constraint, which is incompatible with industrial mass production. All the technologies developed to date are based on the properties of low-pressure plasmas. The process must take place in an expensive, closed-perimeter vacuum system and cannot be used for continuous production lines operating at room temperature, with machines processing fabric 2 meters wide at high speed. [6]

To overcome these restraints, Atmospheric Pressure Plasma Techniques are being developed. This technique provides the highest possible plasma density (in the range of 1 to 5 x 10^{12} electrons cm^{-3}), without the associated high gas temperatures and the cold plasma chemically treats fabric and other substrates without subjecting them to damaging high temperatures. The Atmospheric Pressure Plasma is a unique, non-thermal, glow-discharge plasma operating at atmospheric pressure. The discharge uses a high-flow feed-gas consisting primarily of an inert carrier gas, like He, and small amount of additive to be activated, such as O_2, H_2O or CF_4. [3,7,8]

Plasma Technology in Textile Processing

Plasma technology have been used to induce both surface and bulk property enhancements of textile materials, resulting in improvements to textile products ranging from conventional fabrics to advanced composites. It can improve the functionality of textile materials *such as: -*

Wet ability: there are a lot of investigations on plasma treatment of some textile fibres for changing their wettability properties. For examples, polyester, polypropylene, wool that plasma treatment can improve the ability of these fibres to retain moisture or water droplets on their surface.

Hydrophobic finishing: the treatment of cotton fibre with identified plasma gas such as hexamethyldisiloxane (HMDSO) leads to a smooth surface with increased contact angle of water. The treatment gives strong effect of hydrophobization of treated cotton fibre.

Adhesion: plasma technology can increase adhesion of chemical coating and enhance dye affinity of textile materials.

Product quality: Felting is an essential issue of wool garment due to the fibre scales. Conventional anti-felting gives negative effects on hand feel and environmental issues. Oxygen plasma gives anti-felting effect on wool fibre without incurring traditional issues.

Functionality: different kinds of plasma gases provide special functionality to textile materials such as UV-protection, antibacteria, medical function, bleaching, flame retardancy, etc.

As far as textile is concerns these technology have been shown to enhance dyeing rates of polymers, to improve colourfastness and wash resistance of fabrics. Research has shown that improvements in toughness, tenacity, and shrink resistance can be achieved by subjecting various thermoplastic fibres to a plasma atmosphere. Unlike wet processes, which penetrate deep into the fibres, plasma produces no more than a surface reaction, the properties it gives the material being limited to a surface layer of around 100 Ao. It can be applied to both natural and synthetic fibres as well as to non-woven fabrics, without having any adverse effect on their internal structures.[11,12]

Application of plasma technology in textile

- Desizing of cotton cloths.
- Hydrophobic enhancement of water and oil-repellent textiles
- Anti-shrink-resistance of woolen cloths.
- Hydrophilic enhancement for improving wetting and dyeing.
- Hydrophilic enhancement for improving adhesive bonding
- Removing the surface hairiness in yarn.
- Scouring of cotton, viscose, polyester and nylon cloths.
- Anti-bacterial cloths by deposition of silver particles in the presence of plasma.
- Room-temperature sterilization of medical textiles.[5,6,8,16]

Desizing

Plasma technology can be used to remove PVA sizing material from cotton fibers. In conventional desizing process we use chemicals and hot water to remove size. But desizing with plasma technology we can use either O2/He plasma or Air/He plasma. [8,11 ,12] .Firstly the treatment breaks down the chains of PVA making them smaller and more soluble. X-ray photoelectron microscopy results reveal that plasma treatment introduces oxygen and nitrogen groups on the surface of PVA which owing to greater polarity increase the solubility of PVA of the two gas mixtures that were studied, the results also indicate that O2/He plasma has a greater effect on PVA surface chemical changes than Air/He plasma. [7,8,9,12]

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Water Repellent Finishing on Cotton

The literature on water-repellency and waterproofing is frequently confusing, because the repellency effect observed depends upon the test method and the test conditions used.

- The term 'water-repellent' is actually a relative term because there is always some attraction between a liquid and a solid with which the liquid is in contact.
- The term 'waterproof' is normally taken to represent the conditions where a textile material (treated or untreated) can prevent the absorption of water and also the penetration of water into its structure.[9,10,13]

Felting of Wool

- The process of felting involves relative movement of the fibers which may be caused either by mechanical rubbing or by a series of compression-extension operation.
- Under the influence of these intermittent forces of squeezing, twisting etc., the wet fibers migrate in a preferential root ward direction because of the DFE, and at the same time they tend to curve, loop and entangle with each other. This is the reason of Felting of Wool.
- This process is irreversible. Because of the anchoring effects of the entangling and the differential frictional properties of fibres.
- Crimpiness, flexibility and hygroscopic quality combined with delicacy of fibers, are the most important factors in felting. [14,22]
- Felting is a complex process, and the felting capacity depends not only on the inherent properties of wool, but also on the conditions of the felting process.[8,9,10,15]

Dyeing

Several studies have shown that dye ability or printability of textiles can be markedly improved by plasma treatments. This effect can be obtained on both synthetic and natural fibres. Capillarity improvement, enhancement of surface area, reduction of external crystallinity, creation of reactive sites on the fibres and many other actions can contribute to the final effect depending on the operative conditions. Also production of colors on fibres exploiting diffraction effects has been attempted.[14,15,23,24]

Application	Material	Treatment
Reduced felting	Wool	Oxygen plasma
Crease resistance	Wool, cotton	Nitrogen plasma
Hydrophobic finish	Cotton, P-C blend	AiSiloxane plasma
Hydrophilic finish	PP, PET, PE	Oxygen plasma
Antistatic finish	Rayon, PET	Plasma consisting of dimethylsilane
Improved capillarity	Wool, cotton	Oxygen plasma
UV protection	Cotton/PET	HMDSO plasma
Flame retardancy	PAN, Cotton, Rayon	Plasma containing phosphorus
Improved dyeing	PET	SiCl4 plasma
Improved depth of shed	Polyamide	Air plasma
Bleaching	Wool	Oxygen plasma

Table no 2 Various application of plasma in textile finishing[6-8,21,22]

Advantages of the plasma technology

Textile processing involves many stages like bleaching, finishing etc which adds value to the product. It has many constraints as it is a wet process. It utilizes large volume of water, various chemicals.
It is associated with environment hazards also. Cost of processing is also a main concern. a new technology changes the cost structure of textile processing by reducing the energy consumption, environmental waste and using fewer chemicals offer these benefits to textile processing industry. Off the many advantages of this technology, few are listed as: applicable to most of textile materials for surface treatment.

- Optimization of surface properties of textile materials without any alternation of the inherent proper ties of the textile materials..

- It is dry textile treatment processing without any expenses on effluent treatment. Generation of chemicals, solvents or harmful substances. The consumption of chemicals is very low due to the physical process.

- It is applied for different kinds of textile treatment to generate more novel products to satisfy customer's need and requirement.
- It is simple process which could be easily automated and perfect parameter control.
- As quated by The Human being ,Plasma technologies present an environmentally-friendly and versatile way of treating textile materials in order to enhance a variety of properties such as wettability, liquid repellency, dyeability and coating adhesion.
- Recent advances made in commercially viable plasma systems have greatly increased the potential of using plasma technology in industrial textile finishing.

In India too, efforts have been made at laboratory levels at Indian Institute of Technology, Delhi, Bombay Textile Research Association (BTRA), Mumbai, Wool Research Association (WRA), Mumbai, and Central Silk Technology Research Institute (CSTRI), Bangalore.[3,6,7,23,24]

Conclusions

Plasma, the 4th state of matter, first proposed by I. Langmuir in 1926, now successfully explored in various industries. It has several advantages over traditional technology of textile processing. Plasma technology present an environmentally friendly and versatile way to enhance variety of both surface and bulk properties of textile materials. This technology can be applied to various areas of textile processing vis-à-vis, pretreatment, coloration and finishing. Plasma technology can be used to remove PVA sizing material from cotton fibers, to impart anti-felting property to wool, to enhance dyeability of natural as well as synthetic fibre textiles. Special functional textiles can be produces with the help of this technology. Thus, despite this being costly technology initially, it offers greater production rate, less production cost, better products and most importantly, finishes on fabrics that are either difficult to obtainby other technology or not obtained at all. And above all these, Plasma technology gives the freedom from environmental problems that traditional technologies pose.

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