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Innovative Plasma Technology in Textile Processing: A Step towards Green Environment

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Abstract

Langmuir I. invented plasma terminology in 1926 as 4th state of the matter. Plasma is a special state of matter in which existing at the same time positive ions, negative ions, electrons... and the total positive charge is equal to negative charge. Since plasma is related to high energy charged particles, so people can use plasma to give energy to other compounds for surface treatment, etching, cleaning, sputtering. This technology can be explored in the field of textile processing as an unconventional process. The conventional wet treatments applied in textile processing for fibre surface modification and others are associated with many constraints. These treatments mainly concern with energy, cost and environmental issues. Application of Plasma technology at low temperature in textile processing can prove to be the best alternative for these issues. Various machines and techniques have been developed for generation and application of plasma to the textile materials. The innovative reactions mainly occur on the fibre surface, forming free radicals resulting in surface modification. Plasma technology can be explored in various areas of textile processing e.g. surface modification of fibres, removal of natural/added impurities from the textile material, improvement of wettability of textiles and imparting functional finishing which have been reviewed considerably in this communication.

Keywords: Plasma, textiles, wetprocessing, surface modification, grafting.

Introduction

Plasma, the 4th state of matter is not so a strange thing, it had been first developed by M. Faraday in 1880s and plasma concept was first proposed by I. Langmuir in 1926. The plasma is an ionized gas with equal density of positive and negative charges which exist over an extremely wide range of temperature and pressure. The plasma consists of free electrons, ions, radicals UV-radiation and other particles depending upon the gas used. 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. Plasma, as a very reactive material, can be used to modify the surface of a certain substrate, depositing chemical materials to impart some desired properties, removing substances (plasma cleaning or plasma etching), which were previously deposited on the substrate[1-4]. Today, plasma is used in some consumer product as neon light, plasma TV and so on.

The conventional wet treatments applied in textile processing for fibre surface modification and others are associated with many constraints. These treatments mainly concern with energy, cost and environmental issues. Application of Plasma technology at low temperature in textile processing can prove to be the best alternative for these issues. Unlike conventional wet processes, which penetrate deeply into fibres, plasma only reacts with the fabric surface that will not affect the internal structure of the fibres. Plasma technology modify the chemical structure as well as the surface properties of textile materials, deposit chemical materials (plasma polymerization) to add up functionality, or remove substances (plasma etching) from the textile materials for better applicability. The functional properties of the fabric can be modified by nano scale etching of surface by plasma gas particles.

In textile processing, this technology can be explored in various areas like pretreatment, dyeing and finishing through different methodology vis-à-vis *Glow-discharge method, Corona discharge method* and *Dielectric barrier discharge method* to add functionality and modification of surface properties of textile materials[5].

Plasma technology is applicable to most of textile materials for surface treatment and is benificial over the onventional process, since it do not alter the inherent properties of the textile materials, It is dry textile treatment processing without any expenses on effluent treatment, It is a green process and it is simple process. This technology can generate more novel products to satisfy customer's need and requirement.

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 ionisation energy of the gas. When this level is reached, collisions of the gas particles cause a rapid cascading ionisation, resulting in plasma (figure-2).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, ionised 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.

Plasma is generated when an electrical current is applied across a dielectric gas or fluid (an electrically non-conducting material) as can be seen in figure-1. Artificial plasma produced in air[6] is shown in figure-3.

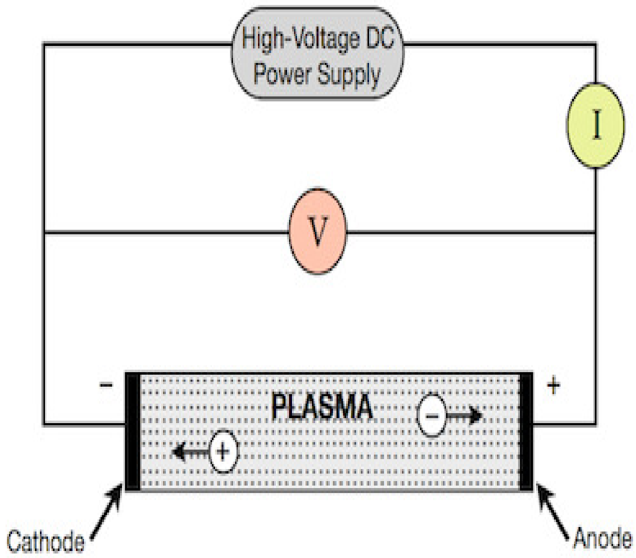

Figure-1
Generation of plasma

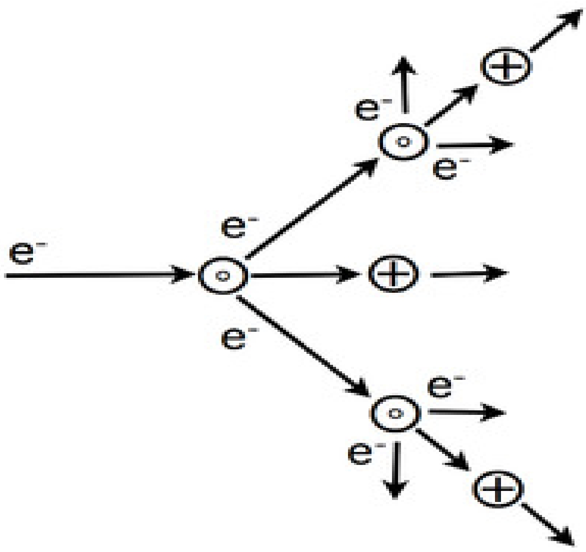

Figure-2
Cascade process of ionization. Electrons are 'e–', neutral atoms 'o', and cations '+'

Figure-3
Artificial plasma produced in air[7]

Different methodology used to induce the ionisation of gases are i. Glow discharge, ii Corona discharge, iii. Dielectric Barrier discharge.

Plasma technology is a surface-sensitive method that allows selective modification in the nm-range. Different reactive species in the plasma chamber (a mixture of electrons, ionised atoms and molecules, photons and residual neutral species) interact with the substrate surface. Depending on the parameters used, different treatments like cleaning, modification or coating occur. Furthermore the plasma process can be carried out in different manners. The substrate can be treated directly in the plasma zone. The substrate can be positioned outside the plasma; this process is called remote process. The substrate can be achieved in the plasma followed by a subsequent grafting. The substrate can be treated with a polymer solution or gas which will be fixed or polymerized by a subsequent plasma treatment.

Advantages of the plasma technology

Textile processing involves many stages like bleaching, dyeing, 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. What if a new technology changes the cost structure of textile processing by reducing the energy consumption, environmental waste and using fewer chemicals? Plasma based technology can offer these benefits to textile processing industry. Off the many advantages of this technology, few are listed as: i. It is applicable to most of textile materials for surface treatment. ii. Optimization of surface properties of textile materials without any alternation of the inherent proper ties of the textile materials. iii. It is dry textile treatment processing without any expenses on effluent treatment. iv. It is a green process without generation of chemicals, solvents or harmful substances. The consumption of chemicals is very low due to the physical process. v. It is applied for different kinds of textile treatment to generate more novel products to satisfy customer's need and requirement. v. It is simple process which could be easily automated and perfect parameter control.

As quated by *The Hindu,* 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.

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: i.*

Wettability: 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, anti-bacteria, 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 A^o. 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.

Application of Plasma Technology in Textile Processing

Due to high restriction in the control of chemical processing of textile materials, the new and innovative textile treatments are demanded. In this regard, plasma technology shows distinct merits due to its environmental friendly and better treatment results. Presently, research institutions are applying plasma technology in textile processing.

Various eras where this technology can be explored includes pretreatments and other wet processes of textiles. Plasma can modify the surface properties of textile materials, deposit chemical materials (plasma polymerization) to add up functionality, or remove substances (plasma etching) from the textile materials and used to produce innovative functional textiles.

Desizing

It is very important that sizes should be removed by desizing to the dyeing and finishing of the woven fabrics. Plasma technology can be used to remove PVA sizing material from cotton fibers. In conventional desizing process utilizes chemicals and hot water to remove size. But desizing with plasma technology involves use of either O2/He plasma or Air/He plasma.

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.

Treatment of Wool by Plasma Technology

Plasma treatment can impart anti-felting effect degreasing, improved dyestuff absorption and increasing wetting properties. Kan C W reported that plasma treatment alone could achieve the best antifelting effect[8]. It reduces the curling effect by etching off the exocuticle that contains the disulfide linkages which increase cross linking and contribute towards shrinkage. This procedure also enhances wetability by etching off the hydrophobic epicuticle and introducing surface polar groups. The increase in surface area of the fiber, recorded with atomic force microscopy, is increased from $0.1m^2/g$ to $0.35m^2/g$. These physio chemical changes decrease the felting/shrinkage behavior of wool from more than $0.2 g/cm^3$ to less than $0.1 g/cm^3$. Plasma treatment increases hydrophilic groups in the wool fibre and the cystine present in the surface layer is converted to cysteic acid[9,10]. Other changes in wool properties are as follows: i. Fibre-fibre friction increases but the differential friction effect is reduced. ii. It does not change the strength and the elongation. iii. Improvements in dyeing and shrink proofing of plasma treated wool

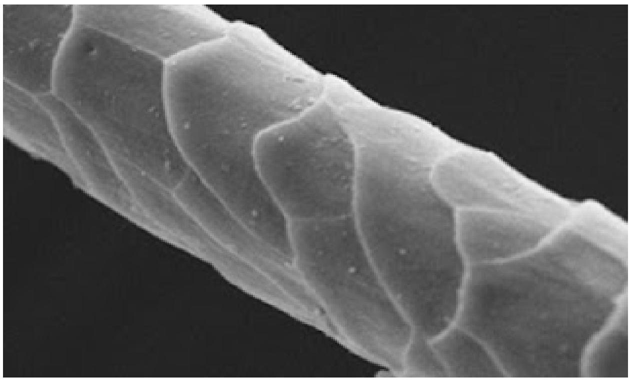

Figure-4
Wool fiber

Dyeing

Several studies have shown that colouration (dye ability or printability) of textiles can be markedly improved by plasma treatments. This effect can be obtained on both synthetic and natural fibres. Wettability and 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.

Dyeability of Natural Fibres: It has been reported that plasma treatment on cotton in presence of air or argon gas increases its water absorbency which in turn increase both the rate of dyeing and the direct dye uptake in the absence of electrolyte in the dye bath.

The contributory factors leading to this increase in dye uptake can be: i. The change of the fabric surface area per unit volume due to the surface erosion. ii. The etching effect of the plasma effect on the fibred mages the fiber surface and also removes surface fiber impurities (e.g. cotton wax or any remaining warp size, etc.). iii. The chemical changes in the cotton fiber surface (leading to carbonyl and carboxyl groups in the fiber. iv. The possibility of the formation of free radicals on the cellulosic chains of cotton. v. Thus the action of oxygen and air plasma treatments modifies the surface properties of cotton and leads to an increase in the rate and extent of uptake of direct dye.

The dye exhaustion rate of plasma treated wool has been shown to increase by nearly 50%. The figure 5 shows that plasma treated wool can achieve 90% exhaustion in 30 minutes as compared to 60 minutes for untreated samples[11].

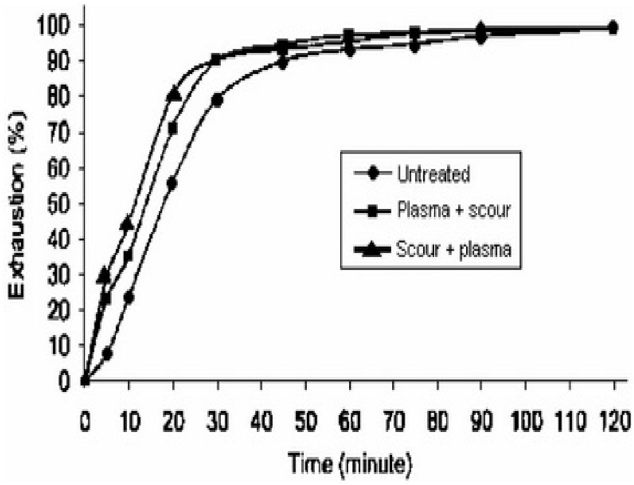

Figure-5
Dyeability of plasma treated wool fibre

The factors for improvement in dyeability can be: i. Increases in the wetability of wool fabric which leads to a dramatic increase in its wicking properties. ii. The disulphide linkages in the exocuticle layer oxidize to form sulphonate groups (which is act as active sites for reactive dyes) which also add to the dyeability. iii. The etching of the hydrophobic epicuticle and increase in surface area also contributes towards the improvement in the dyeability of the fibers.

Dyeability of Synthetic Fibres: In the synthetic fibres, plasma causes etching of the fibre and the introduction of polar groups leading to improvement in dyeability. This has been evaluated through in situ polymerization of acrylic acid in case of polyester, polyamide and polypropylene fabrics.

Plasma-induced surface modification of microdenier polyester produces cationic dyeable polyester fiber. The researchers believe that this technique can lead to a continuous flow system, low energy consumption, and more environmentally friendly consumption, low temperature dyeing technology on polyester substrates.

Polyamide (nylon6) fabrics have been treated with tetrafluoromethane low temperature plasma and then dyed with commercially available acid and dispersed dyes. Dyeing results showed that the plasma treatment slows down the rate of exhaustion but does not reduce the amount of absorption of acid dyes. The dyeing properties of disperse dyes on plasma treated nylon fabric charged markedly when compared with untreated fabric. A slight improvement in colorfastness was seen with the treated sample.

Table-1
Various application of plasma in textile finishing

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

Plasma in Finishing of Textiles

Unlike wet finishing processes, which penetrate deep into the fibres, plasma treatment is restricted to surface reaction and limited to a surface layer of around 100 A^o. Because of this various functionality and properties can be imparted to both natural fibres and polymers, as well as to non-woven fabrics, without having any adverse effect on their internal structures. This leads to produce various types of functional textiles. Various finishing applications of plasma in textiles are given in table-1.

Pane et al reported that plasma treatment can replace traditional method of finishing (washing and coating) for waterproofing of the acrylic fibres for outdoor applications[12].

Plasma can be used for grafting molecules on the fibre surface to impart special functionality to textiles. Abidi N imparted hydrophobic character to lightweight cotton fabric[13] by polymerization using microwave plasma. A polymer layer of about 100 A^o thick is deposited on the cotton fibre surface as a result of this plasma assisted grafting and polymerization (figure 6)

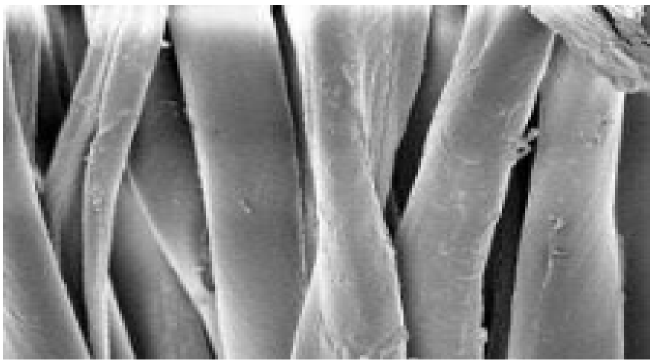

Figure-6
SEM showing polymer layers on cotton fibre

Europlasma, CD Roll 1100/600, CD Roll 1800/600 are some machines based on plasma system tailored for textile surface finishing, developed in Belgium[14]. The costs of these devices are very high, which is a constraint in adopting plasma technology in textiles. If the cost factor is eliminated, this technology will be very important for textile finishing industry.

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 obtain by 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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