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A Case Study

Plasma technology in textiles

■ NIDHI SISODIA **AND** ABHA BHARGAVA

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See end of the paper for authors' affiliations

NIDHI SISODIA
Department of Textile Chemistry, Uttar Pradesh Textile Technology Institute,KANPUR (U.P.) INDIA
Email : sisodianidhi@yahoo.com

■ **ABSTRACT :** This paper reports the studied available on the plasma technology in textiles. Plasma technology modifies the surfaces of textile materials concrete the way for the realization of new materials and of new research zones. This technology is environmentally technique and used for modifying the surface characteristics of a fabric or fibre without altering its basic properties.

■ **KEY WORDS:** Plasma technology, Textile

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Plasma technology is a surface sensitive method and effective only to selective modification in the nm-range. If a textile material is placed in a reaction chamber with any gas and then generated, particles interact with the surface of the textile. In this way the surface is specifically structured, chemically functionalized or even coated with an nm-thin film depending on the type of gas and control of the process.

Moreover being an environmentally technique there is a great demand in the textile industry for problem-free integration of plasma processes in existing production methods. It is a dry technology (Mass/mo Perucca). The plasma treatment on textile material interferes in the following aspects:

- Adhesiveness
- Chemical inertia and affinity
- Wetting capacity
- Bio-compatibility
- Capillarity
- Bond strength
- Lubrication
- Protection and anti-wear
- Sterilization

Plasma :

Partially ionized gas is composed of electrons, ions, photons, atoms and molecules; with negative global electric charge. Plasma is fourth state of matter. When a substance in its gaseous phase absorbs enough energy, the outermost electrons in the atoms will escape the nucleus' control and become free electrons, while the atoms become positively charged (*www.plasmaindia.com*).

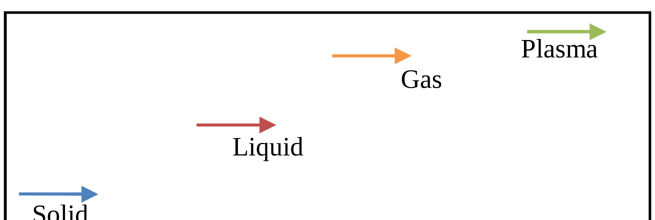


Fig. 1 : States of matter

Irving Langmuir first used the term plasma in 1926. Plasma, as a very reactive material, can be used to modify the surface of a certain substrate (typically known as plasma activation or plasma modification), to impart some desired properties, removing substances (plasma cleaning or plasma etching) (Hocker, 2002).

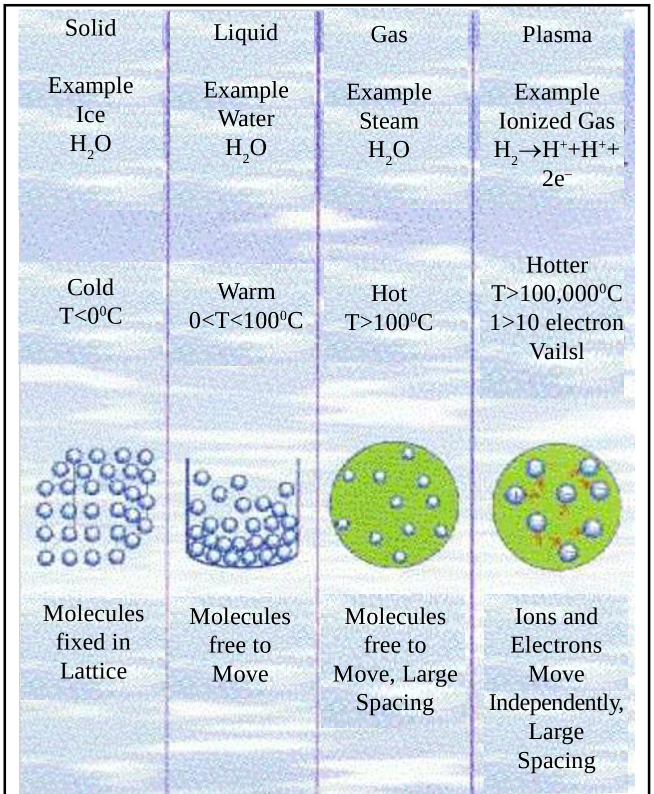


Fig. 2 : Plasma modification

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 (Zaisheng *et al.*, 2013).

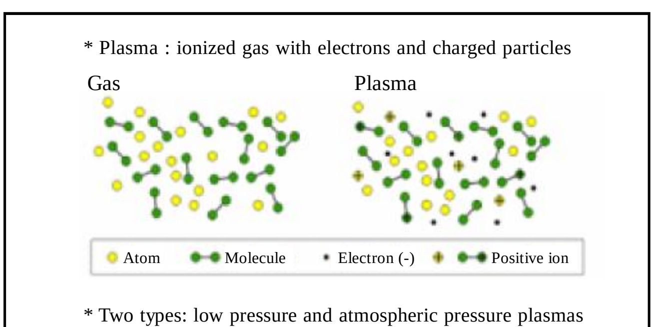


Fig. 3 : Plasma : another state of matter

Many fundamental processes take place during surface treatment of a material: the surface undergoes bombardment by fast electrons, ions, and free radicals, combined with the continued electromagnetic radiation emission in the UV-Vis spectrum enhancing chemical-physical reactions in order to obtain the desired functional properties (*http://www.tikp.co.uk*). The plasma can be used to change the surface wettability which can be changed from hydrophilic to hydrophobic and *vice versa*, to enhance the barrier characteristics, adhesion, dye-ability and printability. Plasma treatment of textile fabrics and yarns is investigated as an alternative to wet chemical fabric treatment and pre-treatment processes, for example, shrink resistance, water repellent finishing or improvement of dye-ability, which tend to alter the mechanical properties of the fabric. Different forms of plasma (*http://www.plasma-us.com*)

– Artificially produced plasma
– Terrestrial plasmas
– Space and astrophysical plasma

Artificially plasma, include fluorescent lamps, neon signs, rocket exhaust, electric arc in an arc lamp, an arc welder or plasma torch and plasma used for surface modification of textiles etc.

Terrestrial plasmas, include ball lighting, St. Elmo's fire, sprites, elves, jets, the ionosphere, the polar aurora.

In Space and astrophysical plasma, include The sun and other stars, the solar wind, the interplanetary med (space between the planets). The Io-Jupiter flux-tube, Accretion discs Interstellar nebulae (*http://www.tikp.co.uk*).

Classes of plasma :

– (Near) vacuum pressure plasma
– Atmospheric pressure plasma

Vacuum pressure plasma :

If a voltage is applied across a nearly evacuated gas chamber, under appropriate conditions, plasma will ignite. Vacuum pressure plasma systems have certain limitations adhered with them in terms of commercial application (*http://www.tikp.co.uk*).

The vacuum creating equipment adds to the cost of treatment and is expensive to run. In addition, the operating pressure range allows only for batch

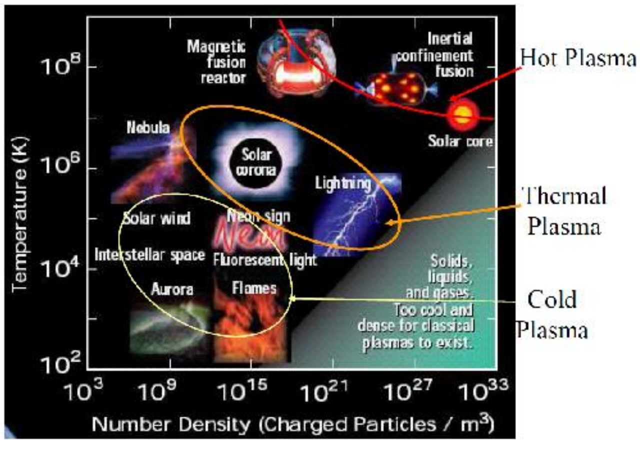


Fig. 4 : Generation of Plasma

processing of material to be possible.

Atmospheric pressure plasma :

Atmospheric plasma is generated under normal pressure. Treatment with atmospheric pressure plasma is thus especially cost-effective and is widely available as an alternative to low pressure plasma. The big advantage of atmospheric plasma is its inline capability.

Generation of plasma :

Plasma can be generated either under low pressure or at atmospheric pressure. Plasma can be created by applying electric field to a low-pressure gas. Plasma can also be created by heat in a natural gas to a very high temperature usually the required temperature are too high to be applied externally. The gas heated internally by injection of high-speed ions or electron that collides with the gas particles increasing their thermal energy.

The degree of ionization, a is defined as

$$\mathbf{a} = \frac{\mathbf{ni}}{\mathbf{(ni + na)}}$$

where, ni is the number density of ions and na is the number density of neutral atoms (Hocker, 2002). The amount, or degree, of ionization is called the "Plasma density".

Generally high plasma density is not suitable for textiles treatment, because plasma energy will burn almost all material, as the temperature of the plasma zone is extremely very high in contrast cold plasma where temperature of plasma zone is near to the room temperature (*http://www.tikp.co.uk*).

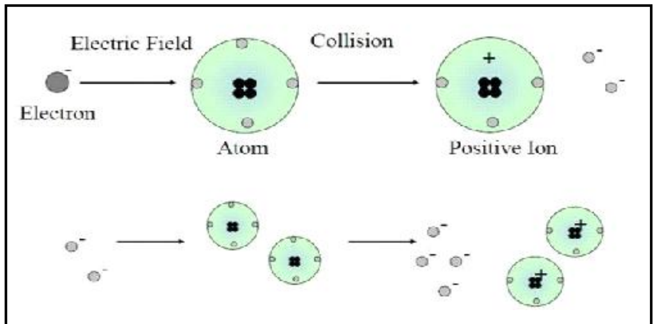


Fig. 5 : Creation of a plasma

Principle of plasma processing :

Different reactive species in the plasma chamber interact with the substrate surface. Research has shown that improvement in toughness, tenacity, and shrink resistance can be achieved by subjecting various thermoplastic fibres to a plasma atmosphere. Recently, plasma treatments have produced increased moisture absorption in fibres, altered degradation rates of biomedical materials and deposition of low friction coatings unlike wet processes, which penetrate deep into the fibres (*http://www.plasma-us.com*).

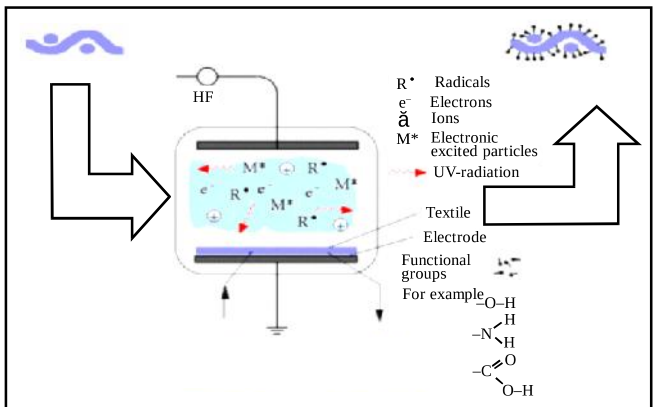


Fig. 6 : Principle of plasma processing

Plasma produces no more than a surface reaction, the properties it gives the material being limited to a surface layer of around 100 angstroms. For example, plasma processing makes it possible to impart hydrophilic or hydrophobic properties to the surface of a textile, or reduces its inflammability (Desai, 2008).

Various applications of plasma in textiles (Desai, 2008).

Various plasma technologies (1) Glow discharge, (2) Corona discharge, (3) Dielectric Barrier discharge

Application	Material	Treatment
Hydrophilic finish	PP, PET, PE	Oxygen plasma Air plasma
Hydrophobic finish	Cotton, P-C blend	Siloxane Plasma
Antistatic finish	Rayon, PET	Plasma consisting of dimethyl silane
Reduced felting	Wool	Oxygen plasma
Crease resistance	cotton	Nitrogen plasma
Improved capillarity	Wool, cotton	Oxygen plasma
Improved dyeing	PET	$SiCl_4$ plasma
Improved depth of shed	Polyamide	Air plasma
Bleaching	Wool	Oxygen plasma
UV protection	Cotton/PET	HMDSO plasma
Flame retardancy	PAN, Cotton	Plasma containing phosphorus

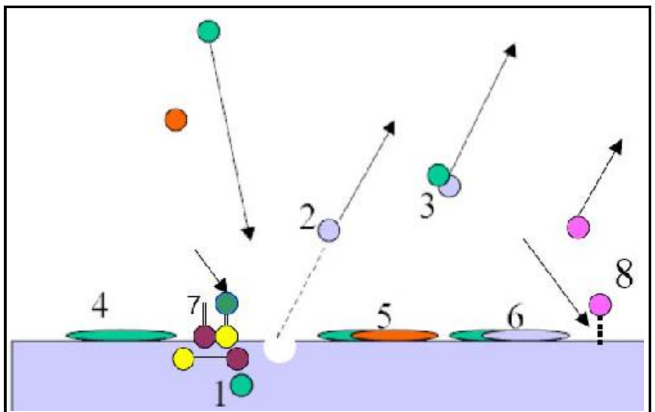


Fig. 7 : Plasma technology

(Desai, 2008).

Classification of plasma processes (*http://www.tno.nl*)

Plasma processes can be conveniently classified into four overall processes:

- Cleaning
- Activation
- Grafting
- Deposition.

Cleaning process :

– Removal of superficial organic compounds by sputtering (Ar plasma) and etching (O_2, air plasmas)

– Metallic oxides reduction by Ar/H2 plasmas

– Plasma sterilization by UV, sputtering and etching

Examples on textiles: desizing or scouring (*http://en.wikipedia.org*).

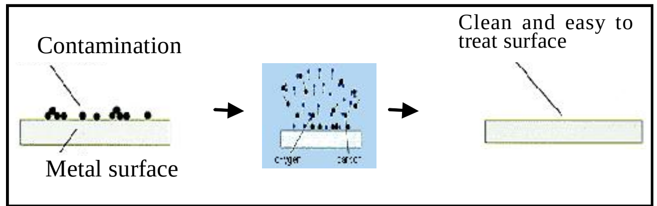


Fig. 8 : Classification of plasma process

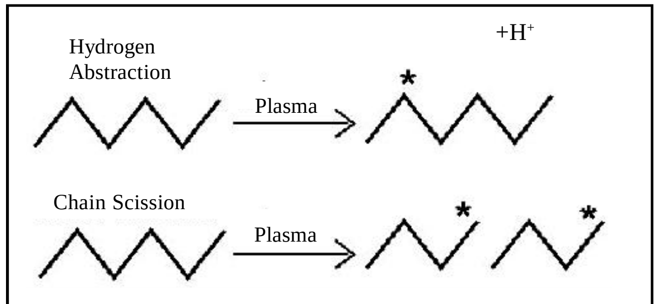


Fig. 9 : Cleaning process

Inert (Ar, He) and oxygen plasmas are used. The plasma-cleaning process removes via ablation. Organic contaminates such as oils and other production releases on the surface of most industrial materials. These surface contaminants as polymers undergo abstraction of hydrogen with free radical formation and repetitive chain scissions, under the influence of ions, free radicals and electrons of the plasma (Sparavign, 2008).

Activation plasma process :

The process refers to the activation of surfaces of polymers by attaching different active species on the surface.

The substrate involves two steps:

– Initiation of radicals in the fibre material.

– Attachment of ionized groups to the initiated radicals (Sparavign, 2008).

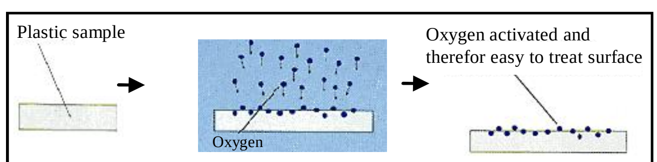
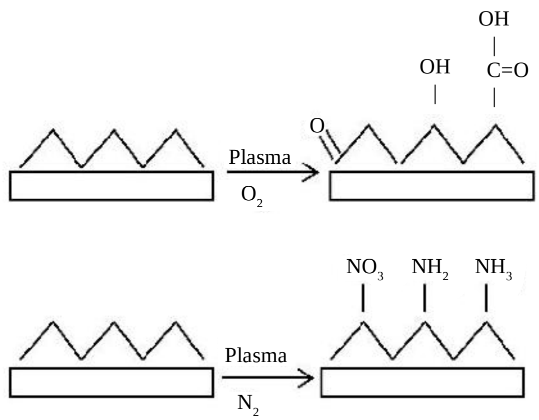


Fig. 10 : Activation process

When a surface is treated with a gas such as oxygen, ammonia or nitrous oxide and others, that does not contain carbon. The primary result is the incorporation of different moieties of the process gas onto the surface



Surface activation by substituting hydrogen in a polymeric chain with other groups such as O, OH, COOH, NO_3, NH_3 etc.

Fig. 11 : Activation process

of the material under treatment the surface may be activated, anchoring on it functional groups such as hydroxyl, carbonyl, carboxylic, amino and amines. Hydrogen abstraction produces free radicals in the plasma gases and functional groups on the polymeric chain (Sparavign, 2008).

Plasma activation (or Plasma fictionalization). Surface activation is a result of following processes

Removal of weak boundary layers :

Plasma removes surface layers with the lowest molecular weight, at the same time it oxidizes the uppermost atomic layer of the polymer.

Cross-linking of surface molecules:

Oxygen radicals (and UV radiation, if present) help to break up bonds and promote the three dimensional cross bonding of molecules

Generation of polar groups :

Oxidation of the polymer is responsible for the increase in polar groups, which is directly related to the adhesion properties of the polymer surface.

Grafting :

An inert gas such as argon is employed as process gas. Many free radicals shall be created on the material surface (Sparavign, 2008).

If a monomer capable of reacting with the free radical is introduced into the chamber, the monomer shall become grafted. Typical monomers are acrylic acid. Allyl amine and allyl alcohol (Fig. 3) (Desai, 2008).

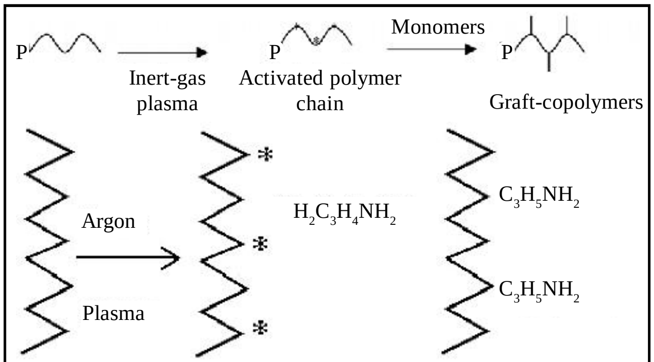


Fig. 12 : Grafting of a monomer on the surface: argon plasma produces radicals on the chain and monomers are grafted on the surface

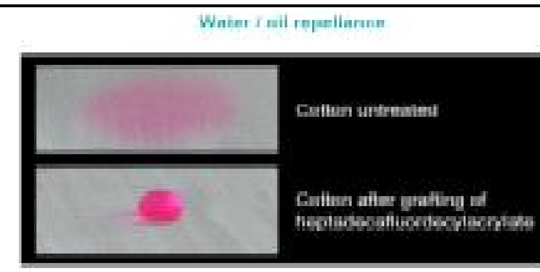


Fig. 13 : Plasma functionalized textile surfaces

Effect of plasma treatment on textiles :

According to requirements the materials to be processed (foils membranes, textiles, polymers, etc.) will be treated for seconds or some minutes with the plasma. Essentially, four main effects can be obtained depending on the treatment conditions.

The cleaning effect is mostly combined with changes in the wettability and the surface texture. This leads for example to an increase of quality printing, painting, dye-uptake, adhesion and so on (*http:// en.wikipedia.org*).

Increase of micro roughness-These effects, for example, on ant-pilling finishing of wool.

Generation of radicals-The presence of free radicals induces secondary reactions like cross-linking. Furthermore, graft polymerization can be carried out as well as reaction with oxygen to generate hydrophilic surfaces.

Plasma polymerization-It enables the deposition of solid polymeric materials with desired properties onto the substrates. Typical example is the incorporation of nitrogen based groups (amines, amides, etc.). This way a permanent primer layer can be realized (Yasuda, 1985).

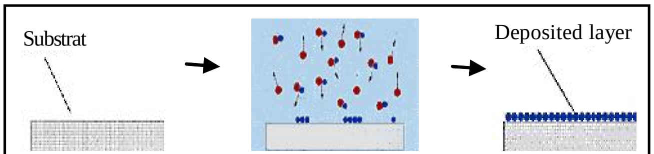


Fig. 14 : Plasma polymerization

Plasma equipment :

A high-frequency generator, which can be in the kHz, MHz or microwave range, then ionizes the gas into plasma, forming an environment that has been referred to as the fourth state of matter' (*http://www.tikp.co.uk*). The formed reactive particles react in a direct way with the surface without damaging the bulk properties of the treated part. In fact, the surface modification is limited to the outermost 10 to 1000 A of the substrate. Plasma systems generally comprise of 5 main components: the vacuum vessel, a pumping group, a gas introduction and gas-control system, a high-frequency generator and a microprocessor-based system controller (*http://en.wikipedia.org*).

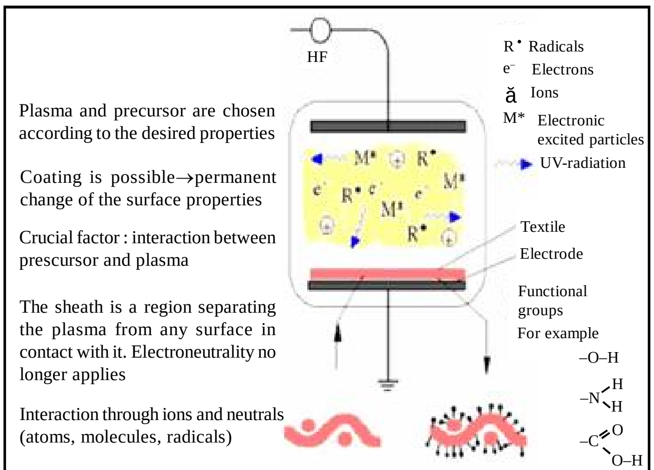


Fig. 15 : Plasma equipment

Ways of looking at plasma technology :

The potential of plasma for textiles can be looked upon from more different engineering, textile, finial and environmental aspects than any other textile related technology. It is therefore essential for the textile industry to get acquainted with all these aspects before decisions on the application of plasma in their company can be made.

The total textile production cycle:

A plasma treatment could replace an existing wet processing step by 3/4th. Examples are treatments for improved wetting and adhesion properties, such as advantageous for dyeing, coating and making composite materials. Saving environment- related costs is a priority. The plasma treatment can be a final step in creating a textile with novel properties. Here textiles can be produced with properties that cannot be induced via wet processing.

Plasma treatment as a means to save water, materials and energy:

This environmental aspect is without doubt the most exposed advantage of plasma technology. Even though such cases are not common, and in view of a continuing cost increase for both water extraction and discharge, plasma technology becomes relatively more cost-effective every day. Other affiliated cost savers are: ¾ reduction of the amount of chemicals needed in wet treatment following the plasma treatment; better exhaustion of chemicals from the bath; reduced BOD/COD of discharged processing water; 1/4 shortening of the wet processing time; this compensates for the possible extra time required for the plasma treatment. Reduction in temperature needed for wet processing; saving heating energy. This adds to the efficient use of energy during the plasma treatment. Extra advantages can be that the finished textile shows better performance and improved fastness properties, *i.e.* has an extra benefit (Plasma treatment of textile fibre (Höcker, 2002).

Plasma treatment as to create unique textile properties:

Due to their high benefit even small textile, batches can be produced at high profit, though perfect process control is necessary. Typically, textiles for medical applications or in the sector of biotechnology are expected to increase in importance. Applications are special selective filtrations, biocompatibility, growing of biological tissues, etc. Especially in this case, high investment costs have a fast pay-off.

Capital investment and the processing costs:

A full width (2,4 m) vacuum plasma reactor which has been designed for the treatment of textiles, is considerably more expensive than the commercial atmospheric reactors currently available, though with the latter type the fabric width is currently limited to 1.7 m. When the processing gas-the gas which is partly ionized in the plasma-is air the related processing costs are as favorable for atmospheric reactors as for vacuum reactors.

Plasma treatment on different fabric surface:

Treatment of cotton with oxygen plasma the specific surface area of cotton after oxygen plasma treatment is increased. On the other hand, the treatment with hexamethyldisiloxane (HMDSO) plasma leads to a smooth surface with increased contact angle of water (sessile drop method) up to a maximum of 1300. Thus, a strong effect of hydrophobisation is achieved. Similarly, when hexafluoroethane plasma is used instead of HMDSO plasma the surface composition of the fibres clearly indicates the presence of fluorine and the material becomes highly hydrophobic.

Plasma treatment of wool to achieve shrink-resistance :

Plasma treatment of wool has a two-fold effect on surface. First, the hydrophobic lipid layer on the very surface is oxidized and partially removed; the tenacity of the fibres is hardly influenced. As the surface is oxidized, the hydrophobic character is changed to become increasingly hydrophilic (Hocker, 2002).

Plasma surface modification in bio-medical applications :

Plasma surface modification can improve biocompatibility, bio functionality. The use of synthetic materials in biomedical applications has increased dramatically during the past few decades. Although most synthetic biomaterials have the physical properties that meet surface modification methods or even exceed those of natural tissue, they often result in a number of adverse physiological reactions such as thrombosis formation, inflammation and infection. Modifying the surface of a material can improve its biocompatibility without changing its bulk properties. Several methodologies have been considered and developed for alter the interactions of biomaterials with their biological environments; plasma surface modification is one of these methodologies (Bhosale *et al.*, 2013).

Plasma treatment of synthetic fibres :

PP is a very interesting material for plasma treatment. PP is a very hydrophobic Material with extreme low surface tension. On the other hand PP is used in a large number of technical applications were an improved wet ability or adhesion properties are advantageous. This is also the case for PP technical textile applications such as filters, medical or hygiene applications, Using an oxidative plasma important improvements in surface tension can be obtained within a very short plasma treatment (Zaisheng *et al.*, 2003).

Applications :

Adhesion promotion :

Many polymers have a low to medium surface energy-examples include polypropylene, polyethylene, polyamide and Teflon. This characteristic makes it difficult to effectively apply adhesives or coatings. With oxygen plasma, one can modify the surfaces of these materials such that they obtain the best possible contact with the adhesive or coating (Sparavign, 2008).

Cleaning :

Conventional cleaning methods can be incapable of removing certain surface films, leaving a thin contamination layer. With plasma treatment, it is possible to achieve out gassing and to completely remove contaminant films. In the same way that weak chemical bonds are removed in the activation process, contamination layers can be eliminated even from complex surfaces. Plasma will remove non-visible oil films, microscopic rust or other contaminants that typically form on surfaces because of stocking or previous manufacturing or cleaning processes (*http://www.tpot.eu*).

Hydrophilic properties :

A specially developed plasma activation process can be used to make a substrate surface hydrophilic. An important secondary effect is fast drying (*http://www.tpot.eu*).

This permanently hydrophilic character can impart to woven or non-woven textiles, the capability to be used as blood filters or filtering membranes for various applications, including micro filtration components for dialysis filter systems.

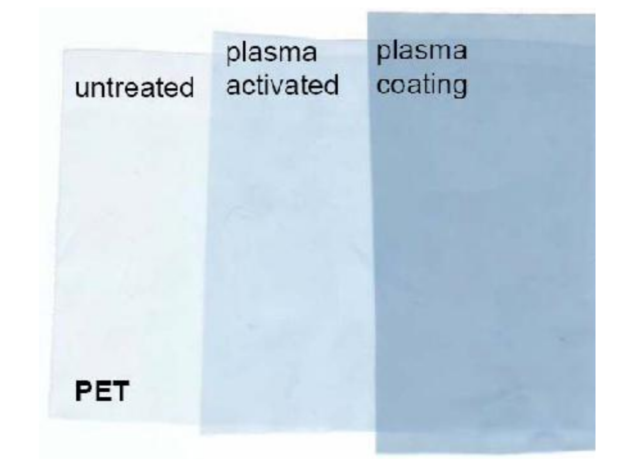


Fig. 16 : Dyeability improving on PET

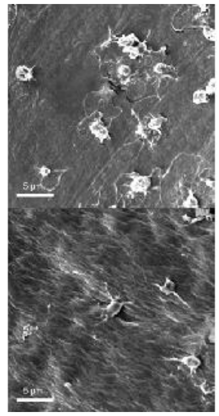


Fig. 18 : Biocompatible textile

Hydrophobicity :

It is possible to plasma polymerize the surface of non-wovens and other textiles so that they become hydrophobic. This technique is becoming popular with device manufacturers looking for replacing conventional methods or improving results through plasma technology. Applications include hydrophobic treatment of paper, textiles and filter elements.

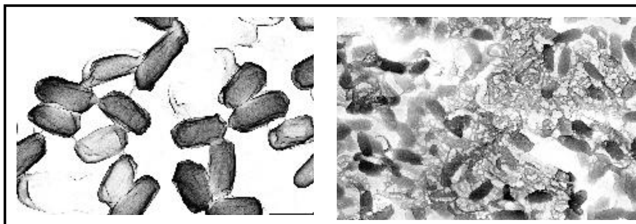
Fig. 17 : Hydrophobicity

Biocompatibility :

The activation of surfaces to prepare them for cell growth or protein bonding is another important application of plasma modification (*http://www.tpot.eu*).

Sterilization :

Sterilization is any process or procedure designed to entirely eliminate micro-organisms from a material or medium. Gas plasmas are increasingly being employed to sterilize the surfaces of medical components or devices. The method uses less toxic materials and can be more cost-effective than irradiation (*http://www.tpot.eu*).



Untreated *B. subtilis* spores **Plasma-treated *B. subtilis* spores**

Fig. 19 : Sterilization

Spin finish removal :

Surfaces are contaminated with spin finish (sizing). The presence of a spin finish can significantly limit performance or largely influence coating adhesion. The combination of the partial cleaning and activation gives good results to wettability or achieved impregnation. A cleaning of the surface is required prior to further production steps. The spin finish present at the surface can be completely removed (100%) (*http://textilelearner.blogspot.in*).

Advantages :

Process-technical aspects :

– Fine-cleaning, activation and coating in one process step

– 3D substrates can also be treated, even fibres and the insides of capillaries

Chemical aspects:

– Chemical variety of the basic substances for plasma polymerization

– No auxiliary agents necessary for polymerization

– High degree of cross linking

– Special fictionalization, also of less active surfaces possible, e.g. hydroxyl, amino, aldehyde, carboxyl groups or grafting of large molecules Layer properties.

– Good adhesion to the substrate.

– Homogeneous layer thickness and structure

– Surface and layer properties can be modified for a specific purpose.

Economic and ecological aspects :

– Low costs for initial materials and routine operation

– Low consumption of chemicals

– Solvent-free, dry process

– Closed process: stable and non-toxic precursors only become highly reactive in the plasma.

Disadvantages of plasma treatment :

– Expensive, high equipment required.

– Treatment tends to produce harmful gasses such as ozone and nitrogen oxides during operation (Deshmukh and Bhat, 2011).

Conclusion :

It is apparent from the above discussion that Plasma is a versatile technology to chemically and physically modify the surface of materials. This technology is used to achieve new or improved properties to textiles and an alternative environmentally friendly technology to complement or substitute several conventional textile processes. Plasma treatments are increasing their presence in the textile industry forseveral applications.so the research and development activities are required in this area to improve strength and aesthetic properties without affecting normal textile properties.

Authors' affiliations:

ABHA BHARGAVA, Uttar Pradesh Textile Technology Institute, KANPUR (U.P.) INDIA

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