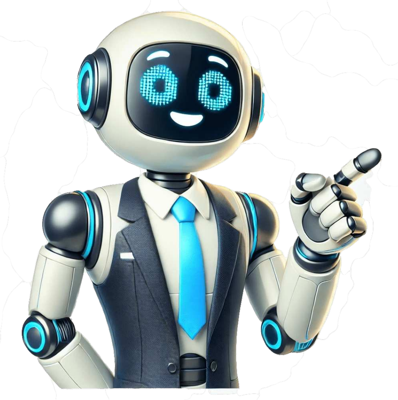

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Fibres & Textiles in Eastern Europe, 28(6) (144) Google Scholar Naebe M, Haque ANMA, Haji A (2022) Plasma-assisted antimicrobial finishing of textiles: A review. Eng 12:145–163Article Google Scholar Plasma surface treatment textiles are revolutionizing the fabric industry by offering environmentally friendly, cost-effective, and highly functional solutions for textile modification. This advanced process enhances fabric properties such as wettability, adhesion, and durability, making it a preferred choice for apparel and aerospace industries. Plasma is the fourth state of matter, where gas becomes ionized, creating a mix of ions and free electrons. This ionization is vital for textile treatment because it allows the surface properties of fabrics to be modified without affecting their structure, enabling better adhesion, dyeing, and coating. Plasma surface treatment technology is based on utilizing this ionized state to alter the surface properties of materials without changing their bulk characteristics. This technology applies non-thermal plasma to textiles, enabling controlled surface activation, cleaning, and coating. Plasma finishes create hydrophobic, hydrophilic, or dirt-repellent surfaces, and allow for functional coatings such as antimicrobial or water-repellent layers, improving the usability and longevity of textiles. Traditional fabric treatments often involve harmful chemicals and excessive water usage. Plasma technology eliminates the need for these, making it a sustainable option for fabric treatment companies. As a dry process, it reduces wastewater and chemical runoff, addressing key environmental concerns. Plasma treatment improves surface wettability, adhesion, and printability. For instance, it enables polypropylene (PP) fibers, which are naturally hydrophobic, to bond with dyes and coatings by introducing polar groups on their surface. Although initial equipment costs may be higher, plasma treatment can save up to 30% in water and energy usage over time, making it a cost-effective solution for textile manufacturers. It also minimizes production time, improving operational efficiency. This versatile technology can be used for various textile purposes, such as: Shrink-resistant wool processing Hydrophobic coatings for outdoor fabrics Antimicrobial treatments for medical textiles Enhanced adhesion for automotive or structural textiles Plasma surface treatment works only on the material’s surface, preserving its bulk properties. This makes it ideal for delicate or high-performance textiles, such as those used in medical or aerospace applications. Plasma treatment’s adaptability has led to its use across numerous sectors. Here are some notable applications: Surface pretreatment allows for the application of coatings such as water-repellent or antimicrobial layers. This is essential for industries that require durable and functional textiles. The plasma process enhances the dyeability of fibers like polyester and polypropylene, making vibrant, long-lasting colors possible without heavy chemical usage. Plasma-treated fabrics are biocompatible for wound dressings, surgical sutures, and other medical applications. They improve adhesion and reduce the risk of infections. Filters made with plasma-treated textiles exhibit superior performance due to enhanced wettability and dirt-repellent properties, which are crucial for industries like healthcare and manufacturing. A plasma finish changes the surface of textiles to make them water-repellent or antimicrobial while still keeping the fabric strong and unchanged on the inside. The primary advantage is its environmentally friendly nature, using less water and fewer chemicals while making textiles stronger, lasting longer, and working better. Plasma treatment of yarn helps yarn stick to things better, take on bright colors, and work in incredible ways, like for special clothes or bandages. KeyLink Technology is a leader in plasma surface treatment systems, providing cutting-edge solutions tailored to diverse industries. Here’s why we’re the preferred choice: Advanced Product Line: We offer customizable solutions for various textile applications, from vacuum plasma systems to online treatment platforms. Sustainability Commitment: Our systems reduce environmental impact by eliminating chemical and water waste. Expertise and Innovation: With years of experience and state-of-the-art technology, we ensure high-quality, reliable solutions for fabric treatment companies worldwide. Explore our cutting-edge plasma surface treatment systems today and discover how KeyLink Technology can revolutionize your textile solutions with unmatched reliability and innovation. In the textile industry, it is still common practice today to treat fabrics with wet chemicals, some of which are harmful to the environment. This is true for the whole manufacturing range, from the yarns for T-shirts up to fabric for space suits designed to protect astronauts from radiation or cold. Another environmental issue is the wide scope of colourants and pigments for dyeing fibres and textiles, as well as the consumption of vast amounts of water in the production of textiles. The waste water primarily comes from the following four production phases:Textile pretreatment (washing, desizing, boiling, bleaching, mercerising, causticizing)Dyeing (continuous/discontinuous)PrintingFinishingIn the course of finishing, the chemicals that are used in the manufacture of the fibres, yarns and fabrics and that are removed from the textile substrate during pre-treatment get into the waste water, as well as the chemicals used in the finishing processes.With a plasma treatment, the surfaces of fibres and processed textiles can be modified in many different ways completely free of hazardous chemicals.

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Presently, research institutions are applying plasmatechnology in textile processing.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. The plasma gas particles etch on the fabric surface in nano scale so as to modify the functional properties of the fabric.Unlike conventional wet processes, which penetrate deeply into fibres, plasma only react with the fabric surface that will not affect the internal structure of the fibres. Plasma technology is to modify the chemical structure as well as the topography of the textile material surface. In conclusion, 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.ApplicationsThere are different methodologies to induce the ionization of plasma gas for textile treatment: Glow-discharge method- plasma gas is produced at reduced pressure. The methodology applies direct electric current, low frequency over a pair of electrodes. Corona discharge method - plasma gas is produced at atmospheric pressure by applying a low frequency or pulsed high voltage over an electrode pair. Dielectric barrier discharge method - plasma gas is produced by applying a pulsed voltage over an electrode pair of which at least one is covered by a dielectric material. Low-temperature plasma technology including both low glowdischarge under reduced pressure as well as dielectric barrier discharge undernormal pressure have been well established in different industrialapplications. The applications on textiles include desizing of woven fabric,adding functionality and modification of surface properties of textile materials. The functionality of textile materials can be improved bythe plasma technology such as: 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. Advantages of the plasma technology It is 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. 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. It is applied for different kinds of textile treatment to generate more novel products to satisfy customer's need and requirement. It is a simple process which could be easily automated and perfect parameter control. Machinery for application of the plasma treatment had been well developed in the market. However, the application of plasma technology for different kinds of textile materials has not been fully commercialised in the industry. Local manufacturers may not have both technical and financial capability to conduct applied research and development of such technology for their own production. HKRITA is now working with research partners to develop the plasma technology for textile treatment and finishing. POTENTIAL USE OF PLASMA TREATMENTS Hydrophobic enhancement of water and oil-repellent textiles.Anti-felting/shrink-resistance of woollen fabrics.Hydrophilic enhancement for improving adhesive bonding.Removing the surface hairiness in yarn.Scouring of cotton, viscose, polyester and nylon fabrics.Anti-bacterial fabrics by deposition of silver particles in the presence of plasma.Room-temperature sterilization of medical textilesWATER REPELLENT FINISHING ON COTTONThe 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.WATER REPELLENCY ON COTTON BY PLASMA TREATMENTTo get water repellent effect on the substrate we can use fluorocarbon gas, siloxanes, and CH_4 gas.The textile the substrate which we have to be functionalized is placed in the plasma chamber and then plasma ignited on to the substrate and then these molecules react with themselves forming a polymer layer directly on the substrate.This process produces a substrate having very low surface tension and thus the surface behaves like a water and oil-repellent fabric.WORKINGHydrophobic coating layers were produced by plasma polymerization of CH_4. The substrate was continuously translated under the plasma deposition region at speed of 5-10 cm min2. The usable plasma area is 1 cm wide and 16 cm long. Helium or argon was used as a carrier gas (5-10 l min21) and CH_4 was used as a reactive gas (10-40sccm). The power was controlled in the range of 250-400 W. Samples were mounted on a computer-controlled moving stage that traveled about 0.3-0.5 cm below the plasma source along the orthogonal direction to the plasma source head. In typical processes, the substrate was repeatedly passed back and forth across the glow-discharge plasma region at a speed of 5-10 cm min21. Here we can either use hexamethyldisiloxane gas, Fluorine, and fluorine-containing gases (CF_4, C_2F_6)   ETC.FELTING OF WOOLThe process of felting involves relative movement of the fibers which may be caused either by mechanical rubbing or by a series of compression-extension operations.Under the influence of these intermittent forces of squeezing, twisting, etc., the wet fibers migrate in the 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 for felting of Wool. This process is irreversible. Because of the anchoring effects of the entangling and the differential frictional properties of fibers.Crimpness, flexibility and hygroscopic quality combined with the delicacy of fibers are the most important factors in felting. 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.ANTI-FELTING TREATMENT ON WOOL BY PLASMA TECHNOLOGYPlasma treatment of wool fibers has shown to reduce this curling effect by etching off the exocuticle that contains the disulfide linkages which increases cross-linking and contribute towards shrinkage. This procedure also enhances wettability 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 0.1m2/g to 0.35m2/g. These physiochemical changes decrease the felting /shrinkage behavior of wool from more than 0.2g/cm3 to less than 0.1g/cm3. For this process, we may use oxygen, nitrogen or mix. Of these gases.DYEINGDyeing and printing: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.E.g.. The dye exhaustion rate of plasma treated wool has been shown to increase by nearly 50%. It has been shown that O_2 plasma treatment increases the wettability of wool fabric thus leading to a dramatic increase in its wicking properties. Also 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 wettability. The etching of the hydrophobic epicuticle and increase in surface area also contributes towards the improvement in the ability of the fibres to wet more easily.when wool is dyed with reactive dyes maximum exhaustion is achieved A possible explanation to this behavior of reactive dyes is due to the increase in sulphonate groups on the fibre surface.USES OF PLASMA TECHNOLOGY IN DIFFERENT FIELDS:The plasma technology is widely used in theelectronic industry,Textiles ,manufacturing,medical researches and technology,optical technologyand many such fields which require quality production, which is sustainable and environment friendly.ENVIRONMENTAL ASPECTS Plasma technology holds tremendous potential to develop processes which can limit the environmental impact of textile processing and contribute towards sustainable development. Savings with plasma treatment can be due to a variety of factors but mostly relate to conservation of water and energy as plasma treatment leads to dramatic reductions in the use of both.Such as in making textile hydrophilic surfaces of fibres to hydrophobic conventionally these treatments are performed by pad/dry/cure treatments which utilize large amounts of water and also require heat to cure the applied chemical.In contrast plasma treatment can achieve the same effect by applying a gas such as oxygen for etching and a fluorocarbon in gaseous state for nanolayering by using comparatively very little electrical power and also performing the same action in much lesser time.And felt treatment of wool which normally requires the application of harmful chlorine based chemical on the surface of the fibres to degrade the epicuticle and exocuticle to increase the hydrophilicity of the fibres and remove their directional scales can be done using a plasma gas treatment such as O_2 . This leads to the elimination of the wet treatment and also avoids the use of environmentally non friendly chlorine based chemicals.Desizing of plasma treated fabrics has shown that by introducing polar groups on the surface of cotton with O_2 plasma the fabric can desized in water at room temperature rather than the 90̊ C bath conventionally required. This can lead to energy savings because heating of the bath will not required for scouring by about 45% from 25 to 40 minutes to achieve similar results .Plasma treated fibres also show quicker and higher exhaustion of dyestuff leading to less processing times and lesser amounts of chemical in waste water, thus leading to more efficient use of energy resources and less hazardous waste in discharge water.ADVANTAGES AND DISADVANTAGES OF PLASMA TECHNOLOGY: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. What if a new technology changes the cost structure of textile processing by reducing 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:Applicable to most of the textile materials for surface treatmentOptimization of surface properties of textile materials without any alternation of the inherent properties of the textile materialIt is dry textile treatment processing without any expenses on effluent treatment.It is a green process without the 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 customers needs and requirements.It is a simple process that could be easily automated and perfect parameter controlDISADVANTAGES OF PLASMA TECHNOLOGYPlasma treatment, however, does have certain drawbacks. The treatment tends to produce harmful gasses such as ozone and nitrogen oxides during operation. This happens due to the formation of free radicals and nascent oxygen during the treatment, which reacts with atmospheric gases to form harmful bi Products. In some cases, contaminations from the substrate such as sulfur from the crystalline links in wool can react with atmospheric oxygen to form oxides of sulfur. It is thereby recommended that plasma treatment systems are installed in well-ventilated areas to ensure that they pose no health risks for the workers working in the surrounding environment.REFERENCES:S. K. Cinta* , S. M. Langade and Sathish . M (Plasma Technology & Its application in textile wet processing) Internatinal Journal of Engineering Research & Technology (IJERT) Vol. IISSN:Issue 5,2278July-0801-2012 Shah J. N. and Shah S. R. (Innovative Plasma Technology in Textile Processing: A step towards Green Environment) Research Journal of Engineering Science Vol . 2(4), 34-39, April (2013)Book (Plasma technologies for textiles) Edited by R. Shishoo   WOODHEAD PUBLISHING LIMITED Cambridge EnglandT-POT PROJECT (Plasma Technology Applied To Textiles) www.leitat.orgPlasma Technology In Textile Processing Conference Paper . June 2004Article by Tanveer malik and Shivendra parmar (Use Of Plasma Technology In Textiles)(The Indian Textile Journal :- www.indiantextilejournal.comWebsites :- www.scribd.comwww.google search enginewww.tecnicaltextile.net Plasma technology has emerged as a groundbreaking innovation that is transforming the textile and apparel industry worldwide. Plasma, often referred to as the fourth state of matter, is an ionised gas consisting of free-flowing electrons, ions, and neutral particles. This unique state of matter offers a wide range of applications in the textile sector, from surface modifications to innovative fabric treatments. In the context of textiles, plasma technology enables precise control over the physical and chemical properties of fabrics, opening up new avenues for enhancing performance, functionality, and aesthetics. By harnessing the power of plasma, textile manufacturers can now address a variety of challenges, from improving wettability and adhesion to imparting antimicrobial properties and reducing environmental impact. Market Insights The global market for plasma surface treatment equipment is projected to grow significantly, from approximately $378.8 million in 2024 to $576.8 million by 2032, at a CAGR of 5.4% [1]. This growth is driven by several factors: Rising Demand for Eco-Friendly Solutions: As consumers become more environmentally conscious, there is an increasing demand for sustainable textile production methods that minimise water usage and chemical waste. Technological Advancements: Continuous innovation in plasma treatment technologies is making them more accessible and effective for various applications within the textile industry. Expansion into New Markets: Beyond traditional textiles, industries such as automotive, healthcare, and sportswear are increasingly adopting plasma technologies to enhance product performance. Current Applications of Plasma Technology in Textiles Surface Modifications One of the primary applications of plasma technology in textiles is surface modification. Plasma treatment can alter the surface characteristics of fabrics, such as wettability, hydrophobicity, and adhesion, without affecting the bulk properties of the material. This capability is particularly valuable in applications were enhancing the interaction between textiles and coatings, dyes, or finishing agents is crucial. For instance, plasma treatment can improve the dyeability of synthetic fabrics like polyester, nylon, and acrylic, leading to more vibrant and long-lasting colours. Additionally, the technology can be used to enhance the adhesion of functional coatings, such as water-repellent or stain-resistant finishes, ensuring better durability and performance. Antimicrobial Treatments Plasma technology has also proven effective in imparting antimicrobial properties to textiles. By introducing reactive species and modifying the surface chemistry, plasma treatment can create an environment that is inhospitable to the growth and proliferation of bacteria, fungi, and other microorganisms. This is especially important in the healthcare, hygiene, and sportswear sectors, where maintaining a high level of cleanliness and odour control is paramount. Environmental Sustainability Plasma technology aligns with the growing demand for more environmentally friendly textile processing methods. Compared to traditional wet-chemical treatments, plasma-based processes typically require fewer resources, such as water and energy, while generating less waste and emissions. This makes plasma technology a compelling choice for textile manufacturers seeking to reduce their environmental footprint and meet increasingly stringent sustainability regulations. Innovative Applications and Future Trends Smart Textiles and Functional Fabrics The versatility of plasma technology extends to the development of smart textiles and functional fabrics. By integrating plasma treatment with advanced materials and nanotechnology, textile engineers can create fabrics with enhanced properties, such as self-cleaning, self-healing, or even energy-harvesting capabilities. These innovative textiles have the potential to revolutionise sectors like healthcare, sports, and personal protection. Plasma-Assisted Textile Recycling As the global focus on sustainability intensifies, plasma technology is also being explored as a solution for textile recycling. Plasma-assisted processes can help break down and separate the individual components of complex textile blends, enabling the recovery and reuse of valuable raw materials. This approach not only reduces waste but also contributes to the circular economy by creating new opportunities for recycling and upcycling. Plasma-Enabled Textile Manufacturing Beyond surface modifications and finishing, plasma technology is now being integrated into various stages of the textile manufacturing process. For instance, plasma-based pretreatments can enhance the wettability and adhesion of fibres, leading to improved yarn quality and better performance in downstream processes, such as weaving and knitting. Pros and Cons of Plasma Technology Pros Cons Environmental Benefits: Reduces water usage and eliminates hazardous chemicals, aligning with sustainability initiatives. High Initial Investment: The cost of plasma treatment equipment can be prohibitive for smaller manufacturers. Enhanced Fabric Properties: Modifies surface characteristics such as wettability, hydrophobicity, and antimicrobial properties without affecting bulk properties. Technical Expertise Required: Implementing plasma technology necessitates specialised knowledge and training. Cost Efficiency: Long-term savings by reducing water usage, chemical costs, and waste management expenses. Limited Depth of Treatment: Primarily affects surface properties; may not be suitable for applications requiring deep penetration into the fabric structure. Improved Dyeing and Coating: Enhances dye uptake and coating adhesion, resulting in better colour fastness and durability of textile products. Potential Equipment Maintenance: Plasma systems may require regular maintenance and calibration to ensure optimal performance. Major Players in Plasma Technology for Textiles Equipment Manufacturers Technology Providers and Consultants Nordson MARCH Henniker Plasma Tantec Surfx Technologies Diener electronic Plasmait GmbH Plasma Technology Systems Europlasma Atmospheric Plasma Solutions As the textile and apparel industry navigates the challenges of environmental sustainability, technological advancements, and evolving consumer demands, plasma technology has emerged as a versatile and transformative solution. From enhancing fabric performance to enabling sustainable manufacturing practices, this innovative approach to textile processing is poised to play a significant role in shaping the future of the industry. As the adoption of plasma technology continues to grow, we can expect to see even more remarkable developments in the years to come. Textiles will become smarter, more functional, and more environmentally friendly, all while maintaining the comfort and aesthetics that consumers expect. The integration of plasma technology into the textile value chain will undoubtedly be a crucial driver of innovation, propelling the industry towards a more sustainable and technologically advanced future. References: Last Updated on 06/04/2021 Arpita Kothari M. Tech. Scholar Department of Textile Technology, NIT Jalandhar, India Email: geniousarpita@gmail.com1. Introduction: The textile industry is searching for innovative production techniques to improve the product quality, as well as society requires new finishing techniques working in environmental respect. Plasma surface treatments show distinct advantages, because they are able to modify the surface properties of inert materials, sometimes with environment friendly devices. For fabrics, cold plasma treatments require the development of reliable and large systems. Such systems are now existing and the use of plasma physics in industrial problems is rapidly increasing. On textile surfaces, three main effects can be obtained depending on the treatment conditions: the cleaning effect, the increase of microroughness (anti-pilling finishing of wool) and the production of radicals to obtain hydrophilic surfaces. Plasma polymerisation, that is the deposition of solid polymeric materials with desired properties on textile substrates, is under development. The advantage of such plasma treatments is that the modification turns out to be restricted in the uppermost layers of the substrate, thus not affecting the overall desirable bulk properties.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. In the 1960s, the main industrial applications of (low-pressure) plasmas have been in the micro-electronic industries. In the1980s their uses broadened to include many other surface treatments, especially in the fields of metals and polymers. In 1980s, in the textile field, low-pressure plasma treatments of a variety of fibrous materials showing very promising results regarding the improvements in various functional properties in plasma-treated textiles. In recent times, commercial applicable atmospheric-pressure plasma processing of textiles is under research.What is Plasma? Plasma is any substance (usually a gas) whose atoms have one or more electrons detached when heat is applied and therefore become ionised. The detached electrons remain, however, in the gas volume that in an overall sense remains electrically neutral. Thus, any ionised gas that is composed of nearly equal numbers of negative and positive ions is called plasma.Figure 1: Plasma: 4th state of matterThe 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 pre-treatment, 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. Plasma technology is applicable to most of textile materials for surface treatment and is beneficial over the conventional process, since it does 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.Gases commonly used for plasma treatments are:Chemically inert (e.g. helium and argon).Reactive and non-polymerisable (e.g. ammonia, air, and nitrogen).Reactive and polymerisable (e.g. tetra fluoroethylene, hexamethyl disiloxane).Principle of Plasma Processing: Plasma technology is a surface-sensitive method that allows selective modification in the nm-range. 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.Types of Plasma: Different plasma based on different things are shown in table 1.Table 1: Types of PlasmaOn the basis of pressureLow pressure (0.01kpa) Atmospheric pressure (100 kpa)On basis of the temperature of electrons and ionsHot plasma (above 10000 degree) Cold plasma (below 100 degree)On basis of frequency of power supplyLow frequency (40kHz) Radio frequency (13.56MHz) Microwave frequency (2.56GHz)2. Plasma Technologies:2.1. Low pressure cold plasma technology: Low-pressure cold plasma technology is also referred to as vacuum plasma technology. This technology has its origin in the processing of semiconductor materials and printed circuit boards (PCB). Soon after its introduction in the electronics industry, the path to incorporation into the textile and nonwoven sectors has been and remains troublesome.The plasma state of a gas – also considered as the fourth aggregation state of matter – can be reached if the gas is under sufficiently low-pressure and when electromagnetic energy is provided to the gas volume. Under those circumstances, the process gas will be partially decomposed into radicals and atoms and will also be partially ionised. Depending on the frequency of the electromagnetic energy, the pressure range in which equilibrium with a high density of charged particles is reached might be different. For the radio frequency range (typically 40 kHz or 13.56 MHz), normally the working gas pressure is kept in the lower 0.1 mbar range, whereas for microwave sources, a working pressure between 0.5 and 1 mbar is often used. In order to effect the plasma treatment in sufficiently pure process gas conditions, a base pressure in the lower 0.01 mbar needs to be reached. This can be done with two-stage roughing vacuum pumps (rotary vane type) or with a dry pump or with a combination of either of those pumps with a roots blower.Plasma can bring several effects to substrates, depending on the plasma mode and the process gases used. There are five major effects fine cleaning, surface activation, etching, cross-linking and coating deposition.Equipment based on this:Figure 2: Roll-to-Roll batch plasma systems.Figure 3: True roll-to-roll web treatmentDevelopment of type of low-pressure plasma is done by:2.1.1. 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 2, 3) Alternatively, a vacuum glow discharge can be made by using microwave (GHz) power supply.2.2. Atmospheric-pressure cold plasma processing technology: Low pressure 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-meter-wide at high speed.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 1012 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.The development of three types of APP that have relevance for textile treatment – the Corona Discharge, the Dielectric Barrier Discharge, the Atmospheric Pressure Glow Discharge.2.2.1. The Corona Discharge: Corona discharges are plasmas that result from the high electric field that surrounds an electrically conductive spatial singularity when a voltage is applied. The high electric field around the singularity, i.e. the point of the needle or the wire, causes electrical breakdown and ionisation of whatever gas surrounds the singularity, and plasma is created, which discharges in a fountain-like spray out from the point or wire. Plasma types are characterized, inter alia, by the number, density and temperature of the free electrons in the system.The discharge is so narrow that the residence time of the fabric in the plasma would be too short for commercial operation and, in addition, the power level that can be applied is extremely limited by the cross-section capacity of the wire and its ability to dissipate heat generated during treatment. Accordingly, in its pure form, corona is far from an ideal textile surface processing medium.Figure 4: Corona discharge2.2.2. Dielectric barrier discharge: In contrast to the asymmetry of the corona system, if a symmetrical electrode arrangement is set up comprising two parallel conducting plates placed in opposition, separated by a gap of ~10 mm, and a high voltage, 1–20 kV, is applied, the gas between the plates can be electrically broken down and a plasma discharge generated. Generally, however, that plasma takes the form of a hot thermal plasma arc less than a millimetre in diameter, which jumps from one spot on one electrode plate to a spot on the opposing electrode. This is useless for textile treatment and would do nothing except burn a hole in the fabric. If, however, one or both of the electrode plates is covered by a dielectric such as ceramic or glass, the plasma finds it much more difficult to discharge as an arc and, instead, is forced to spread itself out over the area of the electrodes to carry the current it needs to survive. This type of plasma is called a Dielectric Barrier Discharge (DBD) and is large area, non-thermal and uniform. Because of charge accumulation on the dielectric, this tends to neutralise the applied electric field thus choking off the plasma, the DBD must be powered by a.c. and is typically driven by high voltage power supplies running at frequencies of 1 to 100 kHz. It is denser than the corona with a typical free electron density of about 1010 electrons/cm3 but the free electrons are slightly cooler at temperatures of 20 000 to 50 000 K. This is a much more attractive candidate for textile processing than the pure corona.Figure 5: Dielectric barrier discharge2.2.3. The atmospheric pressure glow discharge: The third APP type intrinsically capable of meeting the size and temperature constraints needed for textile processing is the Atmospheric Pressure Glow Discharge (APGD). This is analogous in its mode of generation and some key characteristics to the famous low-pressure glow discharge plasma that is the backbone of the global plasma industry and workhorse of a dozen major industries, in particular the omnipresent microelectronics industry, which would not exist without the glow discharge plasma. The APGD is generated by application of relatively low (~200 V) voltages across opposing symmetrical planar or curved electrodes, separated by mm at high frequency, or even very high frequency, radio frequencies 2–60 MHz, much higher than the other plasma types. The electrodes are not covered by dielectric but are bare metal, a feature that enables significantly higher power densities (up to 500 W/cm3) to be coupled into the discharge than can be achieved with corona or DBD.The APGD is denser than the DBD, with typical free electron densities of 1011–1012 electrons/cm3, but the free electrons are slightly cooler at temperatures of 10000 to 20000 K. Textile treatment temperatures can run at 25–50ºC. APGD plasma takes the form of a bright, uniform, homogeneous glow in the region between the electrodes. The application of voltage between metal plates would generally result in generation of a highly undesirable, very high current density and hot plasma arc. By control of the interelectrode gap and the frequency of the driving voltage and, above all, by the use of helium as ~99% of the generation gas, arcing is prevented and a large volume, non-thermal plasma is generated, which is both dense and a rich source of the chemical species needed to carry out textile processing. This amazing gas has several special properties that, in combination, make it uniquely suited for the generation of well-behaved, large volume, cool plasma at atmospheric pressure. Other gases, such as oxygen or nitrogen, are microscopically more complex with many different energetic modes.All in all, helium has been and continues to be probably the best medium for non-thermal APP research as well as being technologically valuable as a route to useful large volume, cool plasmas.Figure 6: Atmospheric pressure glow discharge3. Effect of Plasma on Textile Surface: There are five major effects of which three will be described in detail: fine cleaning, surface activation, and etching, cross-linking and coating deposition.3.1. Surface activation by plasma: Surface activation by plasma is also referred to as chemical grafting (Terlingen, 1993). It never occurs alone, but always occurs during/after plasma cleaning. Indeed, in the case of a substrate subjected to a soft secondary plasma which contains reactive species (e.g. oxygen atoms), the effect of those atoms will be twofold: they will react with organic contamination which is present on the substrate surface. Such organic contamination consists, in many cases, of loosely bound hydrocarbons. Both H and C will react with oxygen and will leave the substrate surface in the form of volatile H_2O and CO_2. Once the surface molecules of a polymer are freed from contamination, they can react with the oxygen atoms which will form carbonyl-, carboxyl- or hydroxyl functional groups on the substrate surface. It is said that the polymer surface has been chemically functionalised.The effect of grafting carbonyl-groups onto a surface of PP, polyethylene (PE), or polyesters such as polyethy leneterephthalate (PET) or polybutyleneterephthalate (PBT) gives rise to an increase in surface energy to levels higher than 68 mN/m immediately after the plasma treatment. This effect is, however, not permanent: it has a certain shelf-life. Once the substrate has been removed from the plasma, and depending on the storage conditions, oxygen atoms will be released again from the surface molecules. This will happen slowly over time. After several days or even several months, the original surface energy of the substrate will have returned. The rate at which this happens depends on the type of substrate: e.g. PP has a fairly good shelf-life of a couple of weeks, whereas silicones show a shelf-life of less than one day. It further depends on the plasma conditions: an intensive plasma treatment will create a higher surface density of functional groups and, as such, the shelf-life will be longer.Plasma activation is being used in several fabric and nonwoven applications in the textile industry:Fabrics for automotive and medical applicationsPre-treatment before dyeingActivation of transportation textile before application of flame-retardant chemistry3.2. Etching by plasma: In order to perform an efficient etching process, a direct plasma is normally needed. In such a configuration, the substrate is bombarded with charged particles (ions and electrons) and apart from a purely chemical effect; the substrate is subjected also to a physical sputtering effect. In the case of textiles and nonwovens, this effect of plasma treatment is not often used.However, there is a certain potential even for fabrics. The textile market is trying to make deep, dark colours and this is not easy to achieve. One way to do this is to reduce the specular component of reflection of the fabric surface after dyeing. A plasma etching leads to a controlled Nano- or micro-roughness, increasing diffuse reflectance and minimising the specular component. In consequence, the dyed fabric will have an intenser darker colour after plasma etching.Etching requires the removal of several hundreds of nanometres and etching processes are therefore slow. Needless to say, this technique is only viable for very high-end textiles.3.3. Thin film deposition by plasma polymerisation: A very important usage of low-pressure vacuum plasma technology is thin film coating deposition by plasma polymerisation. In this specific case, reactive precursor gasses that can polymerise are being used as process gases (Yasuda, 1976). The precursor gases are broken into radicals that react with each other on the substrate surface. The nature of the precursor gases will very much determine the properties of the deposited coating. Coating thickness is normally in the 10–50 nm range (5–30 molecular layers).The very first applications of plasma polymerisation were found in the medical device industry. There are many industrial applications of thin film deposition by plasma polymerisation in the technical textile and nonwoven industry. Roughly, the coatings deposited in those industries can be categorised under either (permanently) hydrophilic coatings or hydrophobic/oleo phobic coatings. In most cases, the deposited coatings give rise to unique products that are difficult or even impossible to produce using other technologies.Application of deposition by plasma on textile:Hydrophobation of nonwovens for filtration applicationsHydrophilic coatings on nonwoven PP for battery separators4. Application of Plasma Technology in Textile: 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.Various eras where this technology can be explored includes pre-treatments, other wet processes of textiles, technical textile and non-woven. Plasma can modify the surface properties of textile materials, deposit chemical materials (Plasma polymerisation) to add up functionality, or remove substances (plasma etching) from the textile materials and used to produce innovative functional textiles.4.1. Desizing of cotton fabric: Plasma technology can be used to remove PVA sizing material from cotton fibres. In conventional desizing process we use chemicals and hot water to remove size. But desizing with plasma technology we can use either O_2/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 O_2/He plasma has a greater effect on PVA surface chemical changes than Air/He plasma.4.2. 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 colours on fibres exploiting diffraction effects has been attempted.4.2.1. 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%. It has been shown that O_2 plasma treatment increases the wetability of wool fabric thus leading to a dramatic increase in its wicking properties. Also, the disulphide linkages in the exocuticle layer oxidize to form sulphonate groups (which are act as active sites for reactive dyes) which also add to the wetability. The etching of the hydrophobic epicuticle and increase in surface area also contributes towards the improvement in the ability of the fibers to wet more easily.4.2.2. 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 (nylon 6) 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.4.3. Textile finishing: 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 Ao. Because of this various functionality and properties can be imparted to both natural fibers 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-2.Table 2: Various application of plasma in textile finishingAPPLICATIONMATERIALTREATMENTHydrophilic finishPP, PET, PEOxygen plasma, Air plasmaHydrophobic finishCotton, P-C blendSiloxane plasmaAntistatic finishRayon, PETPlasma consisting of dimethyl silaneReduced feltingWoolOxygen plasmaCrease resistanceWool, cottonNitrogen plasmaImproved capillarityWool, cottonOxygen plasmaUV protectionCotton/PETHMDSO plasmaFlame retardancyPAN, Cotton, RayonPlasma containing phosphorusPlasma can be used for grafting molecules on the fibre surface to impart special functionality to textiles. Hydrophobic character to lightweight cotton fabric can be done by polymerization using microwave plasma. A polymer layer of about 100 Ao thick is deposited on the cotton fibre surface as a result of this plasma assisted grafting and polymerization. Europlasma, CD Roll 1100/600, CD Roll 1800/600 are some machines based on plasma system tailored for textile surface finishing, developed in Belgium14. The costs of these devices are very high, If the cost factor is eliminated, this technology will be very important for textile finishing industry.4.4. Bio-Medical Applications: New medical products, materials and surgical procedures keep improving current health-care practices. Plasma surface modification can improve biocompatibility and 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. 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. The Process In the plasma surface modification process, a glow discharge plasma is created by evacuating a vessel, usually quartz because of its inertness, and then refilling it with a low-pressure gas, the gas is then energized using techniques such as radio-frequency energy, microwaves, alternating current of direct current. The energetic species in a gas plasma include ions, electrons, radicals, meta stables, and photons in the short-wave ultraviolet (UV) range. Surfaces in contact with gas plasmas are bombarded by these energetic species and their energy is transferred from the plasma to the solid, these energy transfers are dissipated within the solid by a variety of chemical and physical processes as schematically to result in the surface modification.4.5. Antifelting of wool: 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.4.6. Water repellent fabric: Cotton or hemp fabric usually absorbs water immediately. Applying a low-pressure plasma process, the fibre's surface can be altered to make it repel water. After the treatment, drops run freely over the surface while mechanical properties, the visual appearance, and the permeability for water vapour remain unchanged. The surface modification is limited to a very thin layer. A treatment as short as 2 seconds can be sufficient to achieve this effect in a batch process. Continuous treatments with a speed of more than 20 m/min are conceivable. The stability of the modification can be seen in intermitted washing cycles of fluorocarbon treated cotton fabric. After an initial drop, the finishing remains stable for at least two hours at 95°C. The quality of the repellent effect is evaluated by putting water drops to the fabric surface. A value of 1 means that the drops run freely over the surface and do not penetrate into the material while at a value of 3 the water does not penetrate but it needs vibrations to move the drop. Obviously, this evaluation depends also on the nature of the fabric.Figure 7: Water repellence of fabric4.7. Adhesion improvement in laminates and composites: In oxygen plasma the number of functional groups at the surface can be increased which can improve the adhesion to other material. The results are stronger laminates and better composite materials.Figure 8: Adhesion improvement in laminates4.8. Flame retardant fabric: Currently, halogen-containing flame retardants are being banned for ecological reasons. The new kinds of flame-retardant chemistry, e.g. based on organic phosphonate derivatives, are much more expensive. Therefore, their usage should be limited to the absolute minimum. It has been shown that, in the case of plasma-activated fabrics consisting of both natural fibres and polymers, the concentration of flame-retardant chemicals can be reduced considerably without influencing the flame-retardant properties of the treated web. This again leads to considerable cost savings.4.9. Hydrophobation of nonwovens for filtration applications: It is mainly plasma polymerisation for coating deposition that has found its way into the filtration industry. A first example of plasma coating can be found in air filter media both for respirator masks and for filters used in HVAC systems. Such filters consist of several layers of meltblown nonwoven PP, which are electrically charged (electrets). Filtration efficiency for oily particles can be greatly improved by applying a hydrophobic/oleophobic coating prior to electrical charging.Figure 9: Hydrophobation of nonwovens for filtration applications4.10. Hydrophilic coatings on nonwoven PP for battery separators: NiMhydride rechargeable batteries normally use a nonwoven meltblown PP separator web. In order to improve wetting with the electrolyte, some manufacturers are using gamma rays to increase surface energy, but this is an expensive and even hazardous type of treatment. By applying a permanently hydrophilic type of coating out of gaseous pre-cursors, one can increase wetting behaviour of the battery separator considerably.For a 1 min wicking of a plasma-coated material, values between 22 and 25 mm were obtained immediately after plasma coating, whereas the uncoated reference material gave 0 mm (no wicking at all). Commercial reference materials on the market, which were not plasma coated, showed wicking values of only 5 to 10 mm. The samples from the wicking test performed 21 days after plasma coating were immersed in a beaker with 30% KOH solution. The beaker was covered with aluminium foil and was then put in an oven at 70ºC for 7 full days. After this, the samples were rinsed in demineralised water and air dried. Then the wicking test was repeated, showing wicking values of 16–18 mm. Wash resistance of permanently hydrophilic coatings is better than for hydrophobic/oleophobic coatings but is still limited to about 7 wash cycles. Again, in the battery separator application, this is not important.5. Traditional textile processing vs. plasma technology: Table 3 is showing the advantages of plasma technology over textile wet processing.Table 3: Traditional textile processing vs. plasma technology:Plasma processingTraditional wet processingMediumNo wet chemistry involved. Water-based Treatment by excited gas phaseWater – basedEnergyElectricity – only free electrons heated (