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Low Pressure Plasma Treatment of PET and PET/Elastane Fabrics

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Abstract

New orientations have emerged in the textile sector as a result of increasing global competition and environmental problems. Under the scope of new understandings, it is required to bring forward multi-functional, simple and environmental friendly methods that will meet tight economic and ecological demands of today. Plasma technology has become a significant alternative in this sense. This technology may provide great advantages in case it is developed, however, it doesn't receive due consideration. In this study, plasma treatment was applied by using glow discharge plasma system to 100% PET and 95% PET/5% elastane fabrics and then the effects of plasma polymerization on fabric surfaces were tested and analyzed using water and oil repellent finishings. After application of plasma conditions, repellency tests showed that the effect of a reorientation of the fluorinated chains at the surface of PET (Polyethylene Terephthalate) and PET/elastane fabrics remained unchanged and water and oil repellency features were acquired.

Keywords: Plasma; Low pressure; Hydrophobic coating; Water repellent; Oil repellent

Introduction

Traditional textile finishing treatments are processes that require high energy and high water consumption, create pollution, have a high cost, environmentally unfriendly and may adversely affect product performance. Considering all these reasons, multifunctional, simple and clean methods should now inevitably come to the fore in the framework of a new understanding of textile finishing that will meet today's tight economic and ecological requirements. For this purpose, studies on topics which enable changes such as water, energy consumption and process time and environmental pollution reduction are increasingly being continued. In this sense, plasma technology is one of the significant alternatives.

Plasma is a group of positively and negatively charged particles which are totally electrically neutral and move in random directions. A solid material in thermal equilibrium passes to liquid state with temperature increase particularly in constant pressure. If the temperature is increased a bit more, molecules in the gas at a sufficiently high temperature are decomposed in order to form gas atoms moving in random directions freely. If the temperature is increased more, one or more electrons from gas atoms are ejected and by decomposing into charged particles moving freely (positive ions and electrons) the fourth state of matter "Plasma" is formed. (Figure 1) [1]. There are ions, electrons, photons, excited atoms or molecules, radicals, metastable atoms, neutral atoms or molecules in the plasma [2]. It has various advantages recently compared to wet processes such as no water requirement, process occurring in gas state, very little amount of chemical materials used, not causing industrial waste, the process being effective only on fiber surface and enabling energy saving. A solid material in thermal equilibrium passes to liquid state with temperature increase particularly in constant pressure and if the temperature is continued to be increased the liquid passes to gas state. Molecules in the gas at a sufficiently high temperature are decomposed in order to form gas atoms moving in random directions freely.

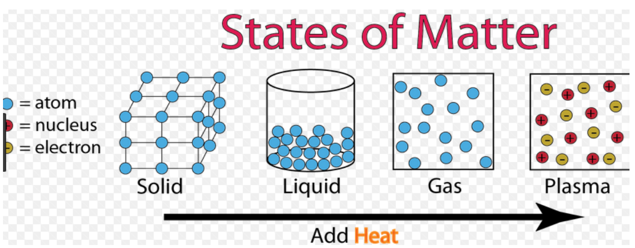

Figure 1: State change occurring as a result of temperature increase of the material.

The plasma was discovered for the first time by Lagmuir, and it can be defined as the fourth state of matter. In general, plasma is a state of excited gas consisting of atoms, molecules, ions, electrons, free radicals and photons, and the negative charges of electrons in the excited state are almost equal to each other. Plasma can not only be classified according to their production methods, but also they can be separated by temperature and pressure of the gas used in obtaining plasma, particle density and degree of ionization. Plasma can be denominated as cold or hot plasma according to temperature; atmospheric or vacuum plasma according to the pressure.

According to the hardware specifications Plasmas are classified as glow discharge, dielectric barrier discharge and corona discharge. The glow discharge used in this study is the oldest plasma method that is produced in the electromagnetic field which is in the range of low voltage frequency interval of (0.4-8.0 kV) and 0-2.45 GHz under gas pressure between 0.1 and 10 MPa.

It can be produced with an inert or reactive gas at low and atmospheric pressure. It has the highest level of uniformity and elasticity in all plasma types. It can be obtained by applying different voltages to a pair or a series of electrons in a closed system [3]. It has become an alternative recently compared to wet processes because of its advantages such as plasma technology, no water requirement, process occurring in gas state, very little amount of chemical materials used, short processing time, not causing industrial waste, not giving harm to the mechanical characteristics of textile material, the process

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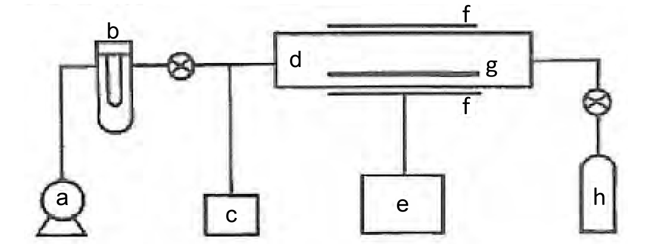
being effective only on fiber surface and enabling energy saving [4-8]. The properties of the material used are significant as plasma treatment is only effective on the surface. The amount of free radicals particularly formed on the surface is closely related to both surface and structural properties of the fiber. It was reported in a study that; the free radical density in the cotton fibers at the end of the cold plasma treatment is more than the wool fibers and the reason of it was the morphological structure of the fiber and the position of the broken chemical bonds. The structure of the material is significant in terms of the efficiency of the treatment as well as the type of the material used. The effects obtained in atmospheric plasma are particularly more evident on thin surfaces [9-12].

Cross-links occurring in the polymer structure of the plasma polymerization are formed as a result of the interaction of reactive groups. At the end of the crosslinking, the polymer chains are bound and form a three-dimensional network (Figure 2). For this process, bonding atoms such as carbon, silicon or sulfur should be included in the process gas. The level of cross-linking depends on process parameters such as pressure, gas flow, applied electrical power, etc.

As a result of these modifications which occur on the surface; the surface is cleaned, the hydrophilicity of the material, the chemical reactivity of the surface and in connection with this adherence to the coatings and matrices is increased.

Hydrocarbon, neocarbon gases, nitrogen-containing monomers or silicon monomers are fed into the plasma chamber and these are subsequently reduced electronically into reactive types. Plasma polymerization is realized by accumulation of reactive types in the plasma as a result of interaction with each other and substrate. There are several parameters that are effective in determining the final products of the plasma polymerization process. These are the accumulation rate, the configuration of the plasma system, the reactivity of the monomer, the flow rate of the gas or monomer gas/vapor, the plasma pressure, the duration of power and plasma processing (Figure 3) [13].

Plasma treatments have been tested in many fields to provide functionality to both natural and synthetic textile products. Most of the research made in the textile industry is focused on polyester and wool. The effects of low temperature plasma used intensively for surface modifications of wool fibers on wool fibers under different conditions were investigated in a study by Kan et al. As a result of the examination of the study results it has been observed that the modification process is not only superficial but also causes changes in the chemical structure of the woolen fabric. It has been observed that there has been a significant



a. Vacuum Pump; b. Cooler; c. Pressure Gauge; d. Plasma Room; e. RF generator; f. Anode and Cathode; g. Sample (fabric); h. Monomer Tank or Gas Tube.

Figure 3: Plasma device assembly.

increase in hydrophilicity, tensile strength and anti-felting properties of the samples treated. Studies on LTP plasmids on polyamide fibers are mostly related to dye affinity, printability and hydrophilicity. The surface energies of polyamide fibers are low. Therefore, difficulties are encountered during handling, coating, painting and printing. Plasma treatment can be used as an alternative in the process of increasing surface energies of polymers. In another study, changes in surface and adhesion characteristics of PA6 fabrics were examined using carbon dioxide and argon gas in a LTP (Low Temperature Plasma). It is possible to increase the hydrophilicity, adhesion, cleanness, sterilization grade, surface energy, and surface friction coefficient of textile products at the end of plasma treatment. In addition to these, effects such as water/oil/stain repellency, flame retardancy, antimicrobial resistance can be obtained with this film layers formed on the surface by using appropriate monomers [14-19]. In another study, the fabrics gained water and oil repellency properties by applying atmospheric plasma treatment on acrylic fabrics [20].

In this study, plasma treatment was applied by using glow discharge plasma system to 100% PET and 95% PET/5% elastane fabrics and then the effects of plasma polymerization on fabric surface was tested and analyzed using water and oil repellent finishings.

Experimental Section

Material

100% PET and 95% PET/5% elastane warp knitted fabrics were used in this study. In the plasma polymerization, acrylic acid of Sigma Aldrich company and as water and oil repellent solutions, a fluorocarbon based polymer with the code of AKEF FC 400 produced by Akkim Kimya company were used.

Plasma treatment

Plasma polymerization is the PICO LF (low frequency, 40 kHz) plasma polymerization system (Diener Electronic GmnH+ Co. KG, Germany). Pressure was operated with 30 Pa. The flow rate of the monomer was maintained constant at 200 cm^3/min during the process. The discharge power was selected as 30W and the treatment time as 20 min.

After plasma treatment implementation, fabrics were weighed and flotte ratio (FO) was selected as 80% and water and oil repellent finish solutions were prepared and applied as 50 g/l according to the soaking method. After the soaking process, the fabric was dried for 15 minutes and the fabrics were fixed in an oven at 150^{o}C for 2 minutes.

Characterization

Oil repellency: Oil repellency test was made according to TS EN

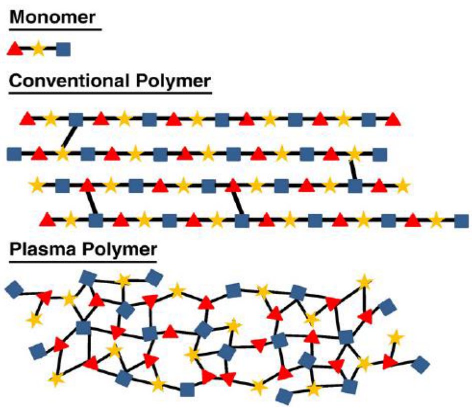


Figure 2: Polymerization arising as a result of Plasma Effect [23].

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ISO 14419: 2010 test method. The first test sample was placed over the white textile drying paper smoothly by keeping the fabric surface on the top and small droplets were carefully dropped to at least 5 different locations of the fabric starting from test liquid with the lowest number. Drops may be 5mm in diameter or 0.05ml in volume. The droplets should be in a distance about 4 cm away from each other and the edges of the dropping bottles should be at a height of 0, 6 cm from the surface during dripping. Drops should be observed at angle of 30s. 45°. The backside of the fabric was observed for any wetting and if there was no wetting at the liquid-surface interface and there was no absorption around the droplets, the next test liquid with higher no was dripped to the fabric with the same method. The droplets were observed for 30s and the reverse direction of the fabric was checked for any wetness. These trials continued until a significant wetting in other test liquids or in the lower layers of the drops are observed or absorption around the drop is observed. Maximum 6 tests can be applied to each test sample. The oil repellency degree of a surface is the numerical value of the highest test liquid number that does not wet the surface within 30 s. The test was conducted at standard atmospheric conditions [21].

Water repellency: The AATCC 79-2000 test method was pursued for the determination of water repellency. According to this method, the dropper was placed 10 ± 1 mm over the fabric and duration of the absorption of fabric for 60s was observed. If the fabric doesn't absorb the water for 60 s, it is reported that the fabric doesn't absorb the water and the water repellency value is high after waiting 4 min more at the end of 300 s. This process was repeated 5 more times and the value was confirmed accordingly [22].

Results and Discussion

Oil repellency

The oil repellency value of 95% PET 5% elastane fabric was recorded as 6.5 while the oil repellency value of %100 PET fabric was recorded as 7. The oil repellency values of both fabrics were found as 300s +, that is to say the fabrics did not absorb the water at the end of 5 minutes. It is possible to see pictures of fabrics in Figures 4 and 5. Images were taken using Galaxy Note 5 smart phone, with a 16 Megapixel rear camera, shot in auto mode without any magnification.

Water repellency

As a result of the treatment, both fabrics didn't absorb water at the end of 60 s. It was observed that water drops remained on the fabrics without being absorbed at the end of 5 minutes for each in total (Figures 6 and 7).

In Table 1, water and oil repellency evaluations and observed fabric appearance values are seen. It was observed that there is not any significant change in appearance for all fabrics samples.

Figure 4: Oil repellency test appearance of PET fabric.

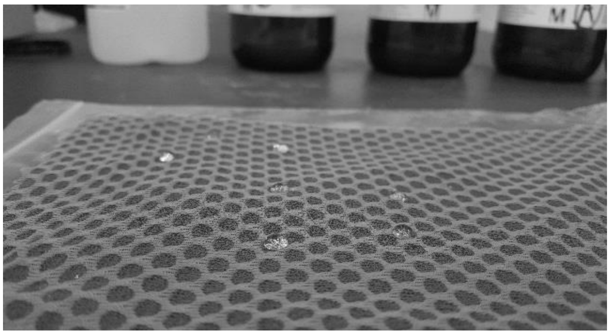

Figure 5: Oil repellency test appearance of PET/elastane fabric.

Figure 6: Appearance of PET fabric at water repellency test after 300 s.

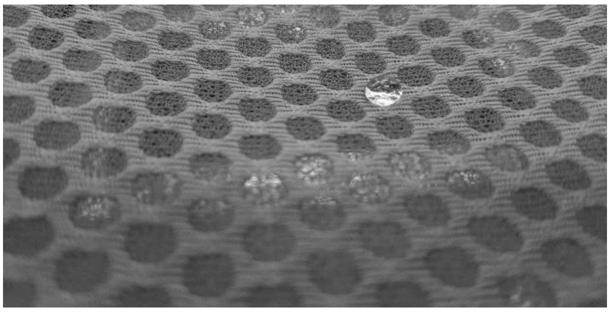

Figure 7: Appearance of PET/elastane fabric at water repellency test after 300 s.

Fabric	Water Repellency Test(s)	Oil Repellency Test (Standard test liquid no)	Appearance
%100 PET	300+	7	Unchanged
%95 PET %5 Elastane	300+	6.5	Unchanged

Table 1: Appearance of fabrics, water and oil repellency test results.

Conclusion

Plasmas are environmentally friendly methods used for treatment of polymeric surfaces. These methods develop surface characteristics of the material without changing the basic characteristics of the material and without using any chemicals or water in a dry system. Improvement of the processes such as wettability, friction, adhesion, reflection of light, water repellency, dirt removal, printing, dyeing and other finishing processes of textile fibers and fabrics using plasma technology have been taken into consideration while conducting the studies. Appearance and handling characteristics of PET and PET/elastane fabrics remained unchanged and water and oil repellency features were acquired. Water and oil repellency values in both types of fabrics were affected positively.

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