Modification of Polyester and Polyamide Fabrics by Atmospheric Pressure Glow Discharge Plasma

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SUMMARY

In this study, the surface of polyester and polyamide fabric were modified by atmospheric pressure glow discharge plasma (APGD) under different operating conditions to improve the hydrophilicity and printability of the fabric. Different plasma treatment gases i.e., air, oxygen (O₂), nitrogen (N₂), argon (Ar), and water vapor was investigated. The treatments of PET and PA fabrics by aspartic (Asp.) and sulfamic (Sulf.) acid were done after plasma treatment in order to improve their printability for basic and acid dyes. The plasma exposure time has been changed to control the extent of plasma surface modification. The efficiency of the plasma treatment was assessed through wettability, K/S, and fastness properties measurements. Surface characterization was performed through FTIR and SEM detection. It was observed that wettability, and the color strength of printed PET and PA fabrics were significantly improved by all plasma treatments.

Keywords: Atmospheric pressure plasma, Dielectric barrier discharge, Polyester, Polyamide, Wettability, Printability, Aspartic acid, Sulfamic acid

INTRODUCTION

Synthetic fibers have become an important part of the current textile industry. A great disadvantage of some synthetic fibers is their low surface energy that causes poor wettability and dyeability. The most popular methods used...
for textile surface treatment are divided into chemical, mechanical, thermal, photochemical and plasma [1].

Plasma treatment of textile is environmentally friendly, it is clean, dry and uses lower energy consumption than equivalent conventional treatments [2, 3]. Plasma modification of polymers has been used to obtain desirable surface characteristics without interfering with the bulk properties of materials [4]. Most plasma treatments have involved low pressure (high vacuum). Low pressure plasma techniques have been investigated and used for textiles and polymer surface modifications by several researchers [5-10].

Atmospheric pressure non-thermal plasma technologies were evolved to fulfil the need of textile industry [11]. The APP technology offers several advantages over low pressure plasma, working at atmospheric pressure, continuous processing of material and possibility of integration with the existing textile processing set up.

Different researches have investigated the effect of (APP) processing on the surface modification of synthetic fibers [12-19].

On the other hand, much research has been done to enhance the dyeability of PET fabrics with basic and acid dyes [21-23] but only few researches concern with plasma effect [24-27].

In previous studies, the effect of poly-diallyldimethylammonium chloride [24], poly-vinyl amine-co-vinyl amide [25], chitosan [40], and acrylic acid [41], were investigated on plasma treated fabrics to improve the dyeability of synthetic fabric to basic and acid dyes, these substances are very cost and need special conditions for treatment, in this study we use cheaper substances and simpler application by using sulfamic and aspartic acid.

In the present work, atmospheric pressure discharge plasma treatment of polyester and polyamide fabrics using five different gases, was investigated, oxygen, nitrogen, argon, air and water vapor was used to modify fabrics wettability and improve their printability with disperse, basic and acid dyes. The discharge condition was adjusted to a discharge current 1.5 mA, 4 kV, at different exposure time, from 1 to 3 minutes to control the extent of plasma surface modification.

After air plasma treatment, PET and PA fabrics were subsequently treated with aspartic acid and sulfamic acid to improve their printability with basic and acid dyes.
MATERIALS AND METHODS

Materials and Chemicals

Mill scoured nylon 6 knitted fabric warp knitting, open width, count: 40/12 denier, flat yarn, weight of square meter: 92.5 g/m², supplied by Golden Tex Company, Egypt.

Mill scoured and heat set polyester woven fabric, count: 150/1 denier, weight of square meter: 100 g/m², supplied by Misr company for spinning and weaving Mahall El-Kobra.

Three different dyes were used in the present work namely Suncid G/Yellow N-3RL (acid dye), Ginacryl Red Violet 3RN (basic dye), and Suncron Navy Blue 2GLS (disperse dye).

Low viscosity sodium alginate manufactured by Fluka Chemical Company, Mepro gum T-8 supplied by Danisco Company, Switzerland, and guar gum, supplied by Morgan Co. Egypt. are used as thickening agents.

Sulfamic acid and aspartic acid, manufactured by Aldrich Chemical Co., Germany are also used.

Acetic acid, citric acid, benzyl alcohol, urea, thiourea, and ammonium sulfate, all reagents are commercial grade of purity, supplied by Al-Nasr Company, Egypt.

Scoural CA, non ionic detergent, supplied by Daico Co., Egypt, is used for washing process.

Method

Atmospheric Pressure Glow Discharge Plasma

The discharge cell shown in Figure 1 consists of two metallic plane-parallel electrodes of 10 cm diameter, one electrode is completely covered with a ceramic material, commercial gypsum, with a diameter of 12 cm and a thickness of 2 mm measured from the metal surface. The discharge gap was fixed at 1 mm. A high voltage transformer (0-10kV) that generates a sinusoidal voltage with a frequency of 50 Hz was used as an electric power supply. The current and voltage waveforms have been measured using 100 MHz digital storage oscilloscope (G Winstek GDS-810S 100MHz) through resistor R1 and R3. The wave form indicated both the value of applied voltage and discharge current, in addition it can indicate if the discharge is in glow or filamentary mode. A limiting resistor R4 was used to limit the current and protect the AC.
power supply. The second electrode was enclosed in a Pyrex container with two ports for gas insertion and exhaustion in which the textile is loaded for treatment. The top of the Pyrex container was covered with a glass plate on which the gypsum covered electrode was rested. The discharge condition could be adjusted to being in the glow mode through adjusting the applied voltage and current.

![Diagram of atmospheric pressure glow discharge](image)

**Figure 1.** Schematic representation for atmospheric pressure glow discharge

**Acid Treatment**

Polyester and polyamide fabrics were subjected to acidic treatment by using 15 g/l aspartic acid or sulfamic acid at 60°C for 30 min after air plasma treatment at 1.5 mA for 3 min in order to improve their printability with basic and acid dyes, samples were rinsed with warm water before printing to remove acid traces from the fabric.

**Printing**

Samples were printed after plasma treatment by using the recipes as shown below:

**Recipe (1):**

- 30 gm Basic dye (Ginacryl Red Violet 3RN 200%)
- 20 gm Benzyl alcohol
- 15 gm acetic acid 30%
- 500 gm mepro gum
5 gm citric acid
X gm water
1000 gm

The prints are then air dried and steamed at 105°C for 30 min

Recipe (2):
30 gm Disperse dye (Suncron Navy Blue 2GLS 200%)
5 gm Citric acid
500 gm Sodium alginate
X gm water
1000 gm

The prints are then air dried and steamed at 130°C (PET) and 105°C (PA) for 30 min

Recipe (3):
30 gm Acid dye (Suncid G/Yellow N-3RL)
50 gm Thiourea
50 gm Urea
5 gm Ammonium sulfate
500 gm Guar gum
X gm water
1000 gm

The prints are then air dried and steamed at 105°C for 30 min

Washing

The printed fabrics are rinsed with running cold water followed by hot water, then the fabrics are washed with 2g/l non-ionic detergent (Scaural CA), at 60°C, for 15 min rinsed with hot water followed by cold water and finally air dried.

Test Methods

The colour strength (K/S) of the printed samples is evaluated by Ultra Scan PRO-Hunter Lab. Spectrophotometer by light reflectance technique and the K/S values of the prints are automatically calculated according to Kobelka-Munk equation [28].

The tensile strength test is carried out according to the ASTM standard test method D1294-95a [29] on a tensile strength apparatus (model 1195).

In order to obtain the wettability or hydrophilicity of the untreated and modified PET and PA fabrics, a water-drop test was applied according to AATCC test
method 39-1980 [30]. The time required for the drop of water to be absorbed into the fabric is referred to as absorbency value.

Infrared (IR) microscopic analysis is carried out by using Bruker Vector 22 (Germany), spectrometer using diffuse attachment to obtain transmission IR spectra.

The SEM photomicrographs were recorded using JEOL, JSM-6510LA analytical scanning electron microscope, to study the changes in the surface morphology of plasma treated fabrics.

The colour fastness to washing, rubbing, and perspiration, are determined according to the AATCC 61-1996, AATCC 8-1996, and AATCC 15-1997 [30] test methods respectively.

RESULT AND DISCUSSION

**Electrical Characterization of the Discharge Cell**

The current and voltage waveforms were measured by 100 MHz digital storage oscilloscope (G Winstek GDS-810S 100MHz) through resistor R1 and R3 using air as a working gas and the data are shown in **Figure 2**.

![The current voltage wave form of the discharge cell](image)

**Figure 2.** The current voltage wave form of the discharge cell

The dash line represents the sinusoidal applied voltage indicated in kV and the filled line represents the discharge current in mA. The form of the discharge
current indicates the type of discharge mode to be in glow mode. Homogenous glow discharge seems to be formed represented by homogeneous current wave with large duration (5-10 ms) nearly in phase with the applied voltage.

The formation of uniform glow discharge at the atmospheric pressure with the existence of gypsum dielectric may be attributed to different possibilities:

- The roughness of the surface forms a large number of sharp edges, which are expected to produce a high local electric field sufficient to cause ionization in the vicinity of the edges through the discharge volume leading to a large number of streamers adds together forming continuous glow discharge.

- Some dielectric materials can trap appreciable amounts of charges uniformly on the surface. When the electric field changes its polarity, the charge carriers are expelled from the surface initiating a diffuse discharge development [31, 32].

**IR Analysis**

From Figure 3, it can be seen that there is a new absorption peak at wave numbers (1507.1 cm$^{-1}$, 1407.78 cm$^{-1}$) that may be characteristic of carboxylate (COO) group in air plasma treated polyester. When the fabric is treated with sulfamic acid after subjected to plasma, some new peaks can be seen when compared with the spectrum of control fabric. The absorption at 610.36 cm$^{-1}$ is due to the sulphonic acid (SO$_2$OH), sulphone (SO$_2$) and sulphonate (SO$_2$OR) groups. The peak at 1090.55 cm$^{-1}$ is due to the stretching vibration of C-N primary amine, RNH$_2$, N$^+$H$_3$, and N$^+$H.

On the other hand, new peaks corresponding to amine and carboxylic acid groups are observed with the use of aspartic acid on PET fabric after plasma treatment. The absorption at 1587.13 cm$^{-1}$ is due to primary amine C-N stretch, RNH$_2$, N$^+$H$_3$, and N$^+$H. The peak at 1519.63 cm$^{-1}$ and 1418.39 cm$^{-1}$ are due to carboxylate (COO) group.

Similar observations can be made in case of polyamide fabric, (Figure 4), treated with air plasma only; the absorption at 1352.82 cm$^{-1}$ is due to carboxylate (COO) group, samples treated with sulfamic acid impart new peaks corresponding to sulphonic acid ((SO$_2$OH) at 1031.73 cm$^{-1}$ and sulphonate group at 1348.96 cm$^{-1}$.

In case of using aspartic acid after plasma exposure on polyamide fabric some new peaks are observed, which can be attributed to C-N primary amine stretch at 1026.91 cm$^{-1}$, C-N tertiary amine stretch and esters at 1159.97 cm$^{-1}$. The absorption at 695.212 cm$^{-1}$, 608.431 cm$^{-1}$ are due to alcohol OH group
out of the plane bends and also a carboxylic acid salt group at 1357.64 can be detected.

![Figure 3. IR spectra of polyester fabric, (a) untreated, (b) 3 min, 1.5 mA air plasma, (c) air/sulfamic acid, (d) air/aspartic acid](image)

**SEM Measurements**

**Figures 5 and 6** show representative SEM micrographs of the untreated and plasma treated PET and PA surfaces. Surface morphology changes significantly after plasma treatment. It can be seen from **Figures 5 and 6a** that the untreated polyester and polyamide fibers respectively look smooth, while **Figures 5 and 6b** show some grooves on the surface of fibers, these results may be due to the removal of some material by etching and roughening
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Figure 4. IR spectra of polyamide fabric, (a) untreated, (b) 3 min, 1.5 mA air plasma, (c) air/sulfamic acid, (d) air/aspartic acid

Effect caused by the bombardment of ions/electrons of oxygen plasma on the surface of PET and PA fibers.

**Wettability**

In this study, atmospheric pressure glow discharge plasma was investigated to improve the surface properties of polyester (PET) and polyamide (PA)
Etching, ablation, cleaning and activation of the surface usually result in improvement of the hydrophilic properties of textiles (1). Much research has successfully used plasma technology for the improvement in wettability, hydrophilicity and adhesion of textiles [13, 18, 33-37].

Wettability expressed as wetting time of untreated and treated fabrics was measured to illustrate the effect of plasma exposure to different gases on the hydrophilicity of both fabrics. Figure 7 shows the wetting times of the PET and PA fabrics modified by different gases. The original untreated PET and PA fabrics have wetting times of 436 and 172 sec, respectively, which means they are quite hydrophobic.

However, the wetting time of PET and PA fabrics decreased significantly after plasma treatment with all glow discharge treatment gases used in this study, especially for the samples after treated with either aspartic or sulfamic acid. The improved wettability can be attributed to the increase in ion bombardment on
the fabric surface which leads to formation of surface-free radicals, increasing the amount of active species formed on the surface and increasing amounts of polar groups, surface oxidation, besides increasing surface roughness [36] according to the kind of gas used in glow treatment.

![Figure 7](image)

**Figure 7.** Wetting time of PET and PA fabrics modified with different glow discharge gases at 1.5 mA for 3 min as well as air discharge/acid after treatment

It could be concluded from **Figure 7** that, the shortest wetting time or the highest hydrophilicity is given by air/aspartic acid treatment; the wetting time is decreased to 7 and 5 sec for PET and PA fabrics respectively; this result is agreement with FTIR results, which clear that aspartic acid induces the carboxyl group (–COOH) and amine group (–NH₂) on the fiber surface. The increased surface polarity enables polar interaction or hydrogen bonding with water molecules, thus increasing the water wettability of the fibers.

In a similar way, air/sulfamic acid treatment shows a significant decrease in the wetting time that reaches 12 and 8 sec. for PET and PA fabrics respectively, which is due to the introduction of (SO₃⁻), and (NH₃⁺) groups, on the fabric surface. It is also observed from the figure that, applying different plasma gases e.g., Ar, O₂, N₂, air and water vapor at the atmospheric pressure on both PET and PA fabrics can improve their wettability to a great extent, this increase in the surface wettability is due to formation of several hydrophilic groups (e.g.,–NH,–CN,–N:N,–C=O,–COOH,–C–OH,–CHO) [36] Beside chain scission, etching, and increasing surface roughness.

**Color Strength**

In this study, we investigate the printability of different modification types of plasma polymerization on PET and PA fabrics with acid, basic and disperse dyes.
Before discussing the results obtained, it is essential to understand the interaction between plasma constituent species and the textile substrate. The nature and extent of the effect of plasma on the substrate are largely dependent on the kind of interactions between the plasma particles and the textile substrate. When the exited and energetic plasma species (ions, radicals, electrons, and metastables) are bombarded on to the textile or polymer surface, they initiate various reactions. Generally, plasma can bring out two types of interactions with the surface [38]. The first type includes chain scission on the surface which results in surface etching, cleaning, or activation. The second type of interaction refers to plasma induce polymerization or grafting. The latter is obtained using non-polymerizing gases like helium, argon, oxygen, air, and nitrogen [1].

Figures 8, 9 and 10 show the effect of different plasma modifications of PET fabric on the increase of K/S of printed fabrics with acid, basic, and disperse dyes respectively.

One can notice from the results that generally there is a significant increase in the color strength of modified polyester fabric with all types of gases used under the investigation. This is due to introducing unsaturated bond/or free radicals on the surface of the fibers, forming polar groups, and increasing surface roughness through preferential amorphous structure ablation processes. As pointed out in the related literature, the surface chemistry of a plasma -treated material changes depending on the plasma conditions.
even if one uses the same gas or monomer plasma, due to different degrees of deposition/etching occurring [36]. So the increase in K/S of modified PET and PA fabrics printed with different dyes used under the investigation is increase profoundly with plasma exposure time irrespective of gas type as it has shown in Figures 8-13. The current data reveals that the maximum K/S is obtained by applying the discharge current 1.5 mA for 3 min with most gases. The same figures indicate that type of gas used for plasma generation plays a key role as it can introduce different functionalities on the textile surface which, consequently affects the dyeing ability.

It can be noticed from Figure 8 that the color intensity of polyester fabric pretreated with nitrogen plasma > oxygen plasma > Ar plasma > air plasma > water vapor plasma upon printing with acid dye. The use of nitrogen gas in plasma treatments may introduce NH2 groups into the fiber, which reflects an increasing absorption of acid dye [39].

In this study, both PET and PA fabrics are subjected to aspartic acid and sulfamic acid treatment after air plasma treatment in order to increase their printability with acid and basic dyes. Air plasma was chosen for this treatment because using air as a working gas in plasma treatment provide several advantage, it is mainly composed of nitrogen molecules (N2) (78%) which dissociated into atomic nitrogen (N) in during plasma formation that is more chemically active than molecular nitrogen and can form several groups on the treated textile surface. In addition, air contains molecular oxygen (O2) (20 %) which dissociate into atomic oxygen (O) that is more chemically active than atomic oxygen during plasma formation, in addition three atoms of oxygen can recombine to form ozone (O3) which has a positive effect on the surface energy of the treated textile. In addition, air is inexpensive so from the economical point of view air is preferable to be used as a plasma media since it gives the same effect on the textile surface as other gases.

It could be concluded from Figure 8, that the maximum K/S is obtained by using air/aspartic acid for PET fabric more than air/sulfamic acid, i.e. the increase in the K/S of PET fabric printed with acid dye reaches 55.33% and 44.17% by using air/aspartic and air/sulfamic acid respectively compared with control sample without plasma or acid treatment. The increase in the color intensity is due to introduce more primary amine groups with both air/aspartic and air/sulfamic acid treatments as is evident from FTIR measurements.

As shown in Figure 9, the color intensity of plasma pretreated polyester fabric printed with basic dye increases in the order oxygen > water vapor > Ar > air > N2 the oxygen plasma incorporates oxygen in the form of C-O and OH (negative sites) in the fiber surface and increases electronegativity. So the dye attraction for cationic (basic) dye with positive sites increases considerably [40].
Figure 9 indicates that air/aspartic and air/sulfamic acid increase the K/S of PET fabric printed with basic dye to 23.14% and 15.70% respectively; this increase in the color strength is due to introducing more carboxylic polar groups on the surface of polyester fabric by air/aspartic treatment or introduce anionic sulphonic groups by air/sulfamic acid treatment, which operating ionic interaction between cationic dyes and these polar groups, as it is shown in Scheme 1, 2 and 3. Despite that, the maximum K/S is obtained by treating
PET fabric by water vapor in plasma treatment for 3 min that gives an increase in the K/S reaches to 28.65%.

Scheme 1.

Scheme 2.

Scheme 3.

Figure 10 shows the results of K/S values of plasma treated polyester fabric printed with disperse dyes. Evidently, the K/S of the polyester fabric was enhanced by the treatment with different plasma treatment gases compared with that of the untreated polyester fabric. The results indicate that argon and oxygen plasma treatments were more effective than air, nitrogen, and water vapor treatments for the surface etching of the polyester fabric. This may be attributed to the degradation of the fabric surface through ion/electron bombardment and the oxidative reaction with activated oxygen atoms as well as free radical formation by argon [41], that make fabric more accessible to water and dye molecules. Thus, it can improve the wettability and diffusion of dye molecules into the fiber.

Figures 11-13 represent the effect of exposure time to the plasma treatment with different gases on the color intensity of treated polyamide fabric printed with acid, basic, and disperse dyes respectively. The obtained results in Figure 11, indicated that the plasma treatment shows high color strength (K/S) on PA fabric using acid dye depending on the structure of the plasma gases, in the order: nitrogen plasma > oxygen plasma > water vapor plasma > air/
aspartic plasma > air plasma > air/sulfamic plasma. Plasma treatment can be responsible for the breaking of the long-chain molecules of polyamide, causing an increase of carboxyl and amine end groups. The amino and carboxylic acid groups will be ionized; attractive interaction operating between the anionic sulphonate groups of the acid dye and the cationic protonated amino end groups of the polyamide, as it is clear in Scheme 4. The maximum increase in the K/S is obtained by nitrogen plasma treatment for 3 min (14.5%), this is due to creating NH groups (positive site) on the surface of PA fabric leading to increase the dyeability with anionic dyes.

**Figure 11.** Effect of exposure time and gas type (at 1.5 mA) on the of K/S of PA fabric printed with acid dye

\[
\begin{align*}
\text{- NH - (CH}_2\text{)}_5 \text{- CO -} & \overset{\text{plasma}}{\rightarrow} \text{H}_2\text{N - (CH}_2\text{)}_5 \text{- COOH} + \text{Dye - SO}_3^- \text{- Na}^+ \\
\text{Acid dye} & \\
& \downarrow \\
& \text{Dye - SO}_3^- \text{- H}_2\text{N - (CH}_2\text{)}_5\text{COOH}
\end{align*}
\]

**Scheme 4.**

\[
\begin{align*}
\text{H}_2\text{N - (CH}_2\text{)}_5 \text{- COOH} + \text{Dye-N}^+\text{(CH}_3\text{)}_2\text{Cl} & \rightarrow \text{Dye - Cl(\text{CH}_3\text{)}_2\text{N - OOC - (CH}_2\text{)}_5 \text{- NH}_2} \\
& \text{Basic dye}
\end{align*}
\]

**Scheme 5.**

The effect of exposure time and gas type on the color intensity of treated polyamide fabric with basic dye is shown in Figure 12. It can be noticed that...
the K/S of PA fabric samples pretreated with oxygen > argon plasma > water vapor plasma > air plasma > nitrogen plasma upon printing with basic dye, the use of oxygen gas in plasma treatments produces negative sites of oxygen ions and /or forms COO⁻ and OH⁻ groups that attract cationic dyes (basic dye). Furthermore, the plasma treatments cause chain scission of polyamide causing an increase of ionized carboxyl and amine end groups leading to ionic attraction between the ionic carboxyl groups of polyamide and more molecules of cationic dyes as it is clear in Scheme 5.

\[ \text{Figure 12. Effect of exposure time and gas type (at 1.5 mA) and type of gas on the of K/S of PA fabric printed with basic dye} \]

On the other hand, the results represented in Figure 12 show that the maximum K/S of PA fabric printed with basic dye are obtained with air/aspartic and air/ sulfamic acid treatments after plasma exposure for 3 min since the increase in the color strength reaches 71.79%.

As is evident from the FTIR measurements, the sulfamic acid incorporates sulphone group (SO2) in the surface of PA fabric, and aspartic acid introduces the carboxylic acid group in to PA fiber, which cause more attraction with basic dye molecules.

As is shown in Figure 13 that there is an enhancement in the color strength of the modified PA fabric printed with disperse dye, where Ar attains maximum increase in the K/S for polyamide fabric followed by air for 3 min. The enhancement in the K/S of plasma treated polyamide fabric is due to the fiber surface modification, and the open structure, which leads to easier and greater dye penetration inside the fiber.
It is worth mentioning that the magnitude of differences in K/S between different plasma treatment gases is not noticeable because disperse dyes do not have any positive or negative sites.

![Figure 13](image)

**Figure 13.** Effect of exposure time and gas type (at 1.5 mA) and type of gas on the increase of K/S% of PA fabric printed with disperse dye

**Fastness Properties**

The fastness properties presented in Tables 1, 2 and 3 indicate that plasma treatment has no change on the fastness properties of polyester fabric printed with different dyes used in the study, although there is some improvement in perspiration and rubbing fastness levels for polyamide fabric printed with acid, basic, and disperse dyes with most of the gases used under the investigation.

**CONCLUSIONS**

Atmospheric pressure glowing discharge plasma treatment was investigated to impart the surface modification of polyester and polyamide fabrics. The influence of different gases, i.e. air, oxygen, nitrogen, argon and water vapor plasma, on the printing properties of polyester and polyamide fabrics by using three dyestuffs; acid, basic and disperse dyes, was studied. The results revealed that the color intensity of the fabrics was increased profoundly with the plasma treatment in all cases, in parallel to the increase in the surface wettabilities. Also the effect of using available and not costly acids with simple application instead of costly substances with difficult application
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Table 1. Colour fastness properties of modified PET and PA fabrics printed with the acid dye

<table>
<thead>
<tr>
<th>Fabric Type</th>
<th>Type of gas used at 1.5 mA for 3 min</th>
<th>Washing Fastness</th>
<th>Rubbing Fastness</th>
<th>Perspiration Fastness</th>
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</thead>
<tbody>
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<td>Polyester Fabric</td>
<td>Untreated</td>
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<td>4/5</td>
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<td></td>
<td>Ar</td>
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<td>Air/sulf. acid</td>
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Table 2. Colour fastness properties of modified PET and PA fabrics printed with the basic dye

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<tr>
<th>Fabric Type</th>
<th>Type of gas used at 1.5 mA for 3 min</th>
<th>Washing Fastness</th>
<th>Rubbing Fastness</th>
<th>Perspiration Fastness</th>
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<tbody>
<tr>
<td>Polyester Fabric</td>
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<td>Air/sulf. acid</td>
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<tr>
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</tr>
<tr>
<td></td>
<td>Water vapor</td>
<td>4/5</td>
<td>4/5</td>
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</tr>
<tr>
<td></td>
<td>Air/asp. acid</td>
<td>4/5</td>
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<tr>
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<td>Air/sulf. acid</td>
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</table>
Table 3. Colour fastness properties of modified PET and PA fabrics printed with the disperse dye

<table>
<thead>
<tr>
<th>Fabric Type</th>
<th>Type of gas used at 1.5 mA for 3 min</th>
<th>Washing Fastness</th>
<th>Rubbing Fastness</th>
<th>Perspiration Fastness</th>
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<tbody>
<tr>
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<td>4/5 4 4 4</td>
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<tr>
<td></td>
<td>Ar</td>
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<td>O₂</td>
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<td>Air</td>
<td>5 5 4/5 4/5</td>
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<td></td>
<td>Water vapor</td>
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<td></td>
</tr>
<tr>
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<td>4 4 4 4</td>
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<td>Ar</td>
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<td>O₂</td>
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<tr>
<td></td>
<td>Water vapor</td>
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</tr>
</tbody>
</table>

are investigated. The results revealed the efficiency of acid treatments with sulfamic acid and aspartic acid after air plasma exposure in enhancing the color strength of PET and PA fabrics printed with acid and basic dyes.

The color fastness properties of the plasma treated PET fabric were excellent and similar to those of the untreated one, while there is some improvement in perspiration and rubbing fastness levels for polyamide fabric.

REFERENCES


