Wettability and Water Vapor Transfer Rate of knitted garments utilizing Non-thermal Atmospheric Pressure Plasma

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Abstract: Sensible and insensible perspiration are crucial aspects of clothing comfort for knitted garments; examined as wettability and WVTR, respectively. Sensible perspiration is when moisture or insensible perspiration is accumulated and transformed into water droplets so called sweat. To maximize comfort, sweat produced during various activities should be able to evaporate through a clothing system. The purpose of this research is to study the effect of non-thermal atmospheric pressure plasma produced in O_2 and air, onto comfort properties of warp knitted PET. Through experimental, wettability and WVTR (Water Vapor Transfer Rate) were examined, as well the durability factor was studied using bursting strength test. Surface morphology of tested fabrics has been detected using SEM (Scanning Electronic Microscopy), finally, FTIS (Fourier transforms infrared spectroscopy) analysis has been obtained searching for development of any new chemical groups. Resultant data, showed wettability values to be accelerated, a negligible effect of ±3% WVTR was obtained, in general, this would enhance wearer comfort properties of knitted garments. It is recommended to utilize lower discharge power, of O_2 Plasma, obtaining the optimum perspiration transfer with minimum loss in fabric strength. Even though, wettability has been enhanced for textile printing purposes, using Plasma in previous studies, none has been used for WVTR and comfort properties.
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1. Introduction

Moisture transfer of the clothing system is either sensible or insensible perspiration; which is recognized as droplets of sweat and water vapor transfer rate WVTR respectively. Horizontal wettability and longitudinal wicking indicate the amount of sensible perspiration absorbed by a textile material away from a particular garment wearer. Inter yarn capillary action, of the textile material, plays the pivot role into getting rid of sensible perspiration, during wearer engagement in numerous activities such as sports. On the other hand, insensible perspiration is mainly verified by the cup method. To maximize comfort, sweat produced during out-door activity should be able to evaporate through a clothing system (Ren and Ruckman 1999).

Wettability has been studied by several researchers using plasma, to enhance printing ability of textile materials, while water vapor transfer rate has not mentioned onto that context. Water vapor transfer, through a fabric under steady state conditions, is primarily dependent on the vapor pressure difference, between the inner surface of the fabric and the outer surface of the fabric, in contact with the environment (Fourt, L. and Harris, M. 1947; Weiner, L. I. 1970; Ruckman 1997). Wettability of synthetic textiles, such as polyester and polyamides, is attributed to the capillary action caused by the inter-yarn spaces. If the water vapor cannot escape to the surrounding atmosphere, the relative humidity of the microclimate inside the clothing increases, causing a corresponding increased thermal conductivity of the insulating air, and the clothing becomes uncomfortable (Holmes 2000). Sensorial perspiration is when moisture or in-sensorial perspiration is accumulated and transformed into water droplets so called sweat (Gabr et al. 2010). Both sensible and insensible perspiration contribute to the comfort properties of garment wearer; in the textile manufactory wet finishing processes are used to accelerate sensible perspiration.

Plasma is partially ionized gas, composed of highly excited atomic, molecular, ionic and radical species with free electrons and photons. In non-thermal atmospheric pressure plasma, although the electron temperature can be much higher, the bulk temperature is essentially the ambient one. The range of applications of plasma technologies in the textile industry varies from the functionalization of surfaces up to the production of exceptional layers. Surface properties like wettability, refractability, colourability and printability or surface hardness can be controlled without changing the bulk character of the substrate (Meichsner J. et al. 2013).

Plasma treatment of textiles is environmentally friendly, clean, dry and uses lower energy consumption than equivalent conventional treatments (Poll et al. 2001; Hwang et al. 2005).

Textile materials treated under the influence of plasma modify the uppermost layers of the substrate, leaving the bulk characteristics unaffected, which further results in desirable surface modification like surface etching depending on the choice of optimized plasma conditions (Jahagirdar, C J and Tiwari, L B 2007. J. and Tiwari, L.B. 2004; Abidi, N. and Hequet, E. 2004; Jahagirdar and Tiwari 2007). The gas-phase radicals produced during the plasma processing have sufficient energy to disrupt the chemical bonds in the polymer surface on exposure, which results in the formation of new chemical species. Modification of textile surfaces by plasma technology can be used to obtain nano-porous structures (Shishoo 2007).

The purpose of this paper is to study the effect of non-thermal atmospheric pressure plasma produced in Oxygen and Air on water vapor transfer rate of warp knitted garments. Clothing comfort of moisture management and durability properties have been investigated, for warp knitted fabrics, in order to achieve durable breathable garments.

2. Material and Methods

Experimental work took place onto three warp knitted fabrics, all of which 100% polyester PET and yarn count 150/1. Dyed knitted Fabrics, mentioned in table 1, were plasma treated prior final softener application.

Table 1: specification of untreated knitted fabrics

Tested fabrics	Yarn density Course x wales /cm^2	Weight g/m^2	Thickness mm	Surface texture
F1	31x25	145	0.475	Dull face and back
F2	30x20	186	0.380	Luster effect innermost surface
F3	32x20	202	0.535	Brushed innermost surface

Plasma treatment

Schematic diagram of the atmospheric pressure dielectric barrier discharge (DBD) cell used for treatment of the fabrics is shown in figure (1). The co-planar DBD cell consists of two parallel plate electrodes. The upper electrode comprises an Aluminum sheet of dimensions 200×200 mm^2 pasted on dielectric glass plate of thickness 1.5 mm. The lower electrode was a stainless steel plate of dimensions 220×220 mm^2. The gap distance between the dielectric glass plate and lower electrode was 3mm. Plasma discharges were operated in oxygen and air as working gases under atmospheric pressure and generated by a 15 kV/30 mA AC power supply of 50 Hz frequency.

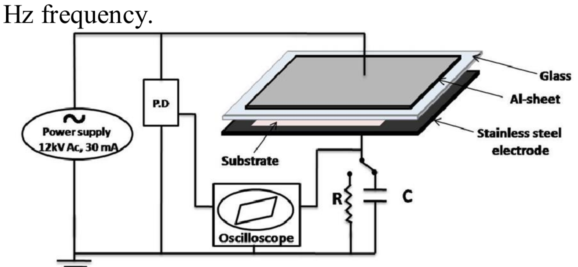

Figure (1) schematic diagram of DBD cell used for treatment of the fabrics

The voltage across discharge electrodes was measured using a resistive potential divider (1:1000) which was connected in parallel with the discharge electrodes. The discharge current has been measured by measuring the voltage drop across resistor R (100Ω) through a digital storage two channel oscilloscope (GW Instek GDS-810S 100MHz). The dissipated power during the discharge has been estimated using 10.2 μF capacitor which is connected in series with the discharge cell to calculate charge flow through the cell. The plasma treatments were performed for 5 minutes at discharge current of 3 and 8 mA for all three mentioned knitted fabrics, as represented in table 2.

Table 2: Plasma treatment various conditions

Oxygen plasma	3mA for 5mins	8mA for 5mins
Air plasma	3mA for 5mins	8mA for 5mins

Thermo-physiological comfort and durability properties of knitted fabrics

Physical properties of Thickness and Weight have been calculated. To investigate the surface modification of the polyester fabric under the effect of plasma treatment, ability of fabric to absorb water was studied; the absorption time of water droplet on the fabric is measured before and after plasma treatment based on BS 4554 standard. Comfort property of WVTR was examined using ASTM 96 standard test methods for water vapor transmission rate (WVTR) of materials. ASTM D 3787:2001 Bursting strength of textiles-ball burst test, for durability purpose; the test was applied at speed 305mm/min, bursting strength was achieved at Newton N, for each examined fabric. SEM using Quanta FEG 250 was measured investigating surface morphology, of untreated and plasma treated samples. Before SEM examination, the fabric surface was prepared on an appropriate disk and coated randomly by a spray of gold. Finally, FTIR (using Burker VERTEX 70 FTIR spectrophotometer), spectra measured in spectral range 400-4000 cm^{-1} in Mid-IR region, with resolution $2cm^{-1}$. Tests were applied for all treated samples, of four different conditions of O_2 and Air plasma shown in table2, measuring the effect of plasma treatment onto function and durability of warp knitted garments.

3. Results and discussion

Current-voltage waveforms of the coplanar DBD cell used in this study were measured at different applied voltages. Figure 2(a) shows an example of these forms at an applied voltage of 5 kV for discharge produced in air. From the figure, it can be seen that, a filamentary discharge was formed, which is characterized by discrete current spikes. These spikes were related to the formation of micro discharges (filaments) of tens of nanosecond duration in the gap space (Kogelschatz 2003). These micro discharges are randomly distributed in the discharge area.

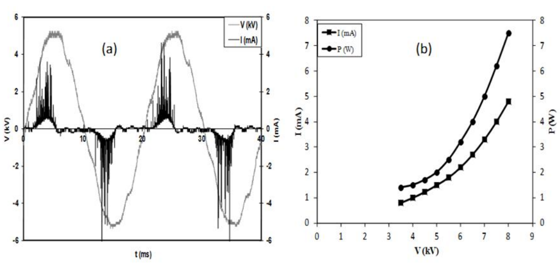

Figure (2) a: current – voltage waveforms of the discharge produced in air and b: variation of the discharge current and power with applied voltage for DBD air discharge

The peak of each individual spike is related to the number of instantaneous microfilaments that were formed at this instant, and hence a high current spike indicates a high number of micro discharges are initiated almost simultaneously. Because high voltages at low frequency tend to spread the micro discharges and increase the number of instantaneous filaments (Kogelschatz et al. 1997), the peaks of the spikes increase by increasing the peak of the applied voltage as we see in figure 2 (b), which shows the variation of the discharge current and consumed power with the applied voltage for discharge produced in air. To calculate the consumed power during the discharge Lissajous diagrams were taken at different applied voltages where the voltage difference between the two electrodes has been measured as a function of the charge on the electrodes. The consumed power is proportional to the area of the parallelogram (Wagner et al 2003). The consumed power has been calculated by multiplying the area of the parallelogram by the frequency of the used AC power supply (50 Hz). The power consumed in the DBD cell has been found to be very low, about 10 W at applied voltage of 10 kV, as shown in figure 2 (b). This result may be attributed to the characterized filamentary discharge behavior where, the time of the filament is very short (few tens of nanoseconds).

Thermo-physiological comfort and durability of knitted fabrics

Plasma has been proved to enhance the hydrophilicity of polyester surface (Lima da Silva et al. 2012; Salem and Morgan 2014). Table 3 shows the wettability values of untreated and treated samples. Thus, it is possible to observe that the untreated samples have a hydrophobic properties since the wettability values were 15.5, 110 and >200 sec. for F1, F2, and F3 respectively. After plasma treatment there was a significant increase in the wetting properties. This behavior is due to incorporation of polar functional groups as confirmed by IR analysis in previous studies (Salem and Morgan 2014). It has been reported that non-thermal atmospheric pressure plasma consists of neutral particles, ions, excited particles and electrons, which can possibly break molecule chains, generate new functional groups and /or morphological alteration in the polymers surface, such as microporosity (Yaman et al. 2009). The introduction of water compatible functional groups (-COOH, -OH, -NH2, etc) increases hydrophilicity of polyester (Retcl, M. 2008).

Table 3: Wettability values for untreated and plasma treated warp PET knitted fabric

Plasma gases	Condition of treatment	Wettability (sec.)		
		F1	F2	F3
---------	Untreated	15.5	110	>200
O_2	3mA-5min.	2	7.6	>200
O_2	8mA-5min.	1.15	4	>200
Air	3mA-5min.	0.93	5	>200
Air	8mA-5min.	0.35	2	>200

Note: >200Seconds means non-wettable fabric, PET is denoted for Polyester.

It can be concluded from table 3 that, increasing the discharge power of oxygen or air, plasma leads to increase water absorption on the treated fabric, hence more hydroxyl and carboxyl groups were formed on the surface of polyester fabric.

The increase in wettability reaches to 92.6% and 96.4% for the treated F1 and F2 respectively by 8mA of oxygen for 5 min., similar behaviour was observed by using air plasma. The time of water absorption on the treated fabric reduced sharply after exposure of the samples to air plasma. This behaviour can be associated to the higher concentration of nitrogen found on the fabric surface after this treatment. Furthermore, nitrogen can bind with hydrogen and carbon to form amines (NH and C"N) that have high polarity which gives more hydrophilicity to polyester fabric (El.Zeer and Salem 2014; El.Zeer et.al 2014).

In the context of thermos-physiological comfort, F1 showed a dramatic increase into absorbing water away from human body, followed by F2 which has showed the same behaviour towards absorbing sweat away from human body. The most accelerated behaviour is seen after the Air plasma treatment in comparison to O_2 plasma treatment, as well the increase in current from 3 to 8mA resulted into faster absorbing process of the warp knitted fabrics. F3 with the brushed lining did not show any wettability, even under the most severe conditions with plasma, neither Air nor O_2 treatments. This shows the positive effect of plasma into increasing moisture absorbance of warp knitted garments, at the same time this is not the case for brushed garments, where negligible effect appears.

Water Vapor Transfer Rate WVTR

Percentages of WVTR have been calculated for tested fabrics; resultant data showed negligible change in the WVTR for all tested samples after O_2 and Air plasma treatment, when compared to untreated samples; this was shown in Table 4 below for F1, F2 and F3. In hot environments or at high activity levels, evaporation of sweat becomes an important path of body heat loss, and fabrics must allow water vapour to escape in time to maintain the relative humidity between the skin and the textile material. If resistance to water vapour diffusion is high, the water vapour transfer is impeded and discomfort sensation of dampness and clamminess may arise (Huang J. 2015).

Both O_2 and Air Plasma represented a maximum change of ±3%, into WVTR was observed for tested fabrics, for 3mA and 8mA currents used. The results show no effect of plasma onto fabrics breathability, even though wettability was rapidly accelerated for both fabrics F1 and F2.

Table 4: WVTR results for untreated and plasma treated polyester fabric

Plasma gases	Condition of treatment	WVTR (%)		
		F1	F2	F3
---------------	Untreated	80.4	76.4	65.4
O_2	3mA-5min.	79	77.03	65.4
O_2	8mA-5min.	79.3	74.03	67.13
Air	3mA-5min.	78.13	76.8	64.8
Air	8mA-5min.	78.2	75.9	67.13

Burst Strength

The burst strength results for untreated and plasma treated polyester fabric are shown in table 5. Burst strength N values have decreased, for F1 under the effect of different plasma treatment conditions. O_2 plasma at higher current of 8mA, showed a much decrease in strength, by 30% from 652N to 458N, while a not as much decrease of 14% in burst strength for O_2 Plasma treatment at lower current of 3mA. On the other hand, the Air plasma at 8mA resulted on a decrease of just 12%, this shows that the O_2 plasma negatively affects polyester strength compared to Air plasma, and this is worse when current is higher at the same duration. That was not the case in previous study, by Raslan et al. 2011, where resultant data showed that it seems that the plasma impact damage to the fabric is negligible. As well a study by Jahagirdar C J and Tiwari L B 2007, concluded that polyester fabric can be modified suitably by treating with plasma so as to make it water repellent without losing its original strength. Those studies are in line with the other two tested fabrics, F2 and F3, when O_2 and Air plasma are utilised.

Table 5: Burst strength results for untreated and plasma treated polyester fabric

Plasma gases	Condition of treatment	Burst strength (N)		
		F1	F2	F3
---------------	Untreated	652	1171	1125
O_2	3mA-5min.	561	1182	1113
O_2	8mA-5min.	458	1019	958
Air	3mA-5min.	587	1184	1136
Air	8mA-5min.	574	1112	1078

F2 showed almost the same amount of strength, for all treatments, it even showed higher values when current is minimum; this can be due to the surface characteristic of this particular fabric, where it has a lustrous effect, assumed that a reflection of the plasma might have occurred at 3mA current. This was not the case when the current is raised to 8mA, as this will lead to increase in the discharge power and the plasma becomes more efficient at creating a high density of free radicals by dissociating the molecules through electron collisions and photochemical processes (Shishoo 2007; Raslan et al. 2011).

Fourier transforms infrared spectroscopy analysis (FTIR)

In order to investigate the chemical effect of O_2 and Air plasma treatment on the surface of the polyester fabric, FTIR analysis was carried out. Figures3, 4&5 demonstrate the FTIR spectra of untreated and F1 processed polyester fabric. Careful investigation, of IR-spectra of untreated and plasma treated samples, revealed that no observable changes in the positions of the characteristic peaks compared to untreated polyester fabric except for changes in the relative intensities of the stretching vibrations of the functional groups, which determines its various properties. This was the same results as in a study by Jahagirdar, C J and Tiwari, L B 2007.

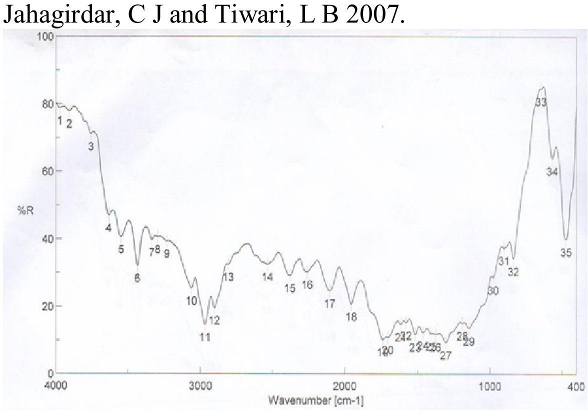

Figure 3: FTIR Spectrum of Untreated Warp PET

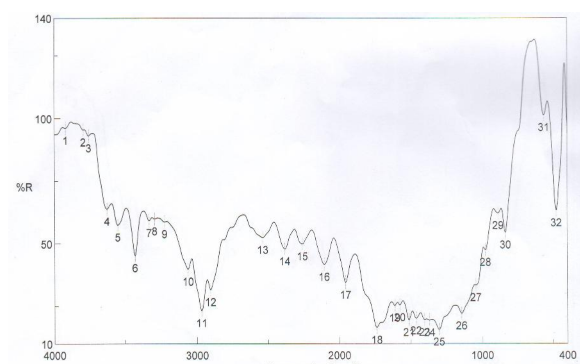

Figure 4: FTIR Spectrum of Plasma Oxygen treated Warp PET

However, one can note that the intensity of O-C=O (carboxylic groups) peak, in Figures 4&5, was significantly higher than that in Figure 3. This increase, in the absorption intensity, indicates the introduction of more polar groups such as –COOH, on the surface of the treated fabric. These results, may be attributed to the fact that some of the C-C bonds in the polyester fabric surface could be broken, under the effect of the energetic particles flux generated in the oxygen plasma then, the carbon radicals, formed by the abstraction of hydrogen atoms generated in the plasma or in the air by electron impact dissociation (Cheng et.al 2006, Ferrero 2003), resulting in the formation of oxygen-containing polar groups on the fabric surface.

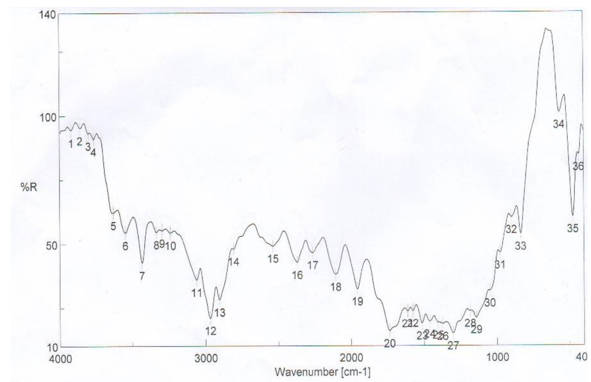

Figure 5: FTIR Spectrum of Plasma Air treated Warp PET

These results are in a good agreement with wettability values, since the introduction of oxygen containing polar groups on the fabric surface changes the nature of the fabric from hydrophobic to hydrophilic, as reported in the literature (Cui & Brown 2002, Jasso et. al 2006, Pappas et. al 2006, Shin et. al 2007).

Scanning Electronic Microscopy SEM

Morphology of polyester yarns has been studied, merely for F1 where the highest wettability was achieved, when compared to the rest of the studied warp knitted polyester. Untreated and plasma treated samples were scanned, both O_2 and Air plasma at current 8mA for the duration of 5mins. Figures 6, 7 &8 below show resultant images of mentioned various states of F1, at 8000x magnification.

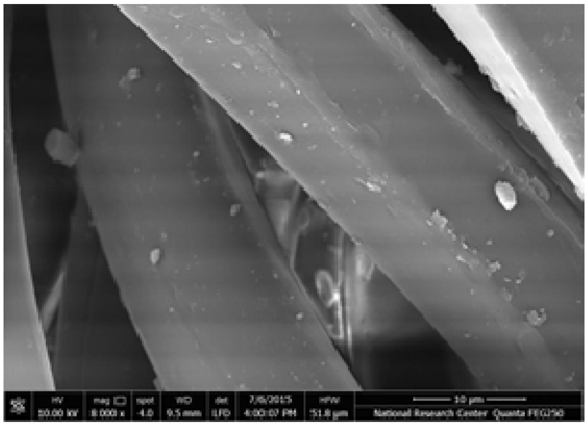

Figure 6: SEM of Untreated F1 magnified.

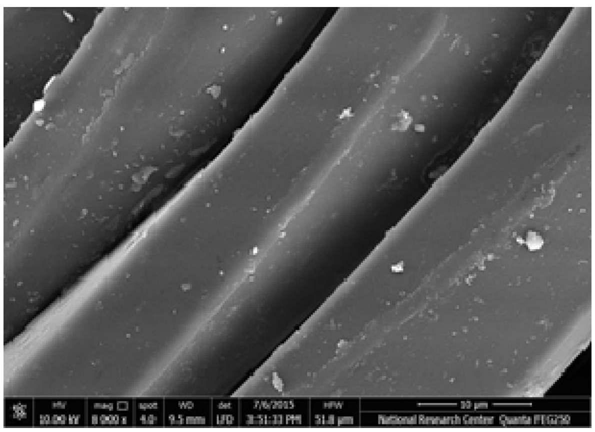

Figure 7: SEM of Plasma O_2 treated (8mA for 5min) F1

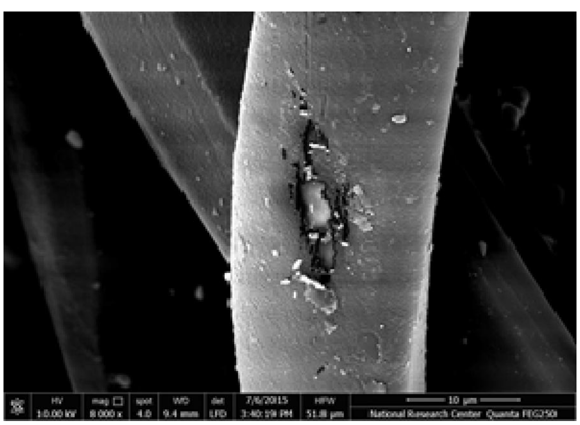

Figure 8: SEM of Plasma Air treated (8mA for 5min) F1

Despite, the amount of loss in bursting strength was 30% for F1, under the effect of O_2 plasma treatment, and the loss in strength decreased just to 12%, for the same fabric F1 when treated with Air plasma. SEM showed cracks within F1 fibers' surface for Air treatment more than O_2 treatment, Figures 7&8. Wettability results, in Table3, showed F1 as the highest absorbing characteristics, when plasma treated using Air at 8mA for 5min., while in the SEM Figure8, shows badly damaged surface of plasma treated polyester. As well, Table 5 of the burst strength showed a decrease in strength by 12%, caused by Air plasma treatment, into that particular fabric F1 compared to F2 and F3.

Etching of Air plasma should have caused polyester yarns to soften its edges, causing yarns to become more rounded, as seen in Figure 8, and by turn increasing the capillary action caused by the inter yarn spaces, wicking more sensible perspiration away from the human body, increasing wettability, at the same time from Table 4 the WVTR percentage almost did not change. Previously, it was mentioned that some grooves on the surface of fibers, these results may be due to the removal of some material by etching and roughening effect caused by the bombardment of ions/electrons of oxygen plasma on the surface of PET (Salem and Morgan 2014). From the SEM, Figures 6 and 7, of the untreated warp polyester and O_2 plasma treatment respectively, it can be observed that the morphology of F1 yarns has not changed.

4. Conclusion

In conclusion, O_2 treatment at low current, 3mA with 5min duration, showed a better resultant data, for warp knitted PET. Wettability has been accelerated to achieve a 2sec. result, for a droplet of water to be absorbed, a loss of 14% bursting strength, physical properties of weight and thickness have not been affected by plasma treatment. In case of higher current of 8mA, SEM morphology of PET yarns have been cracked when Air treated compared to O_2. No significance of new chemical groups were developed; this is due to the etching possessed by O_2 or Air Plasma treatment, onto treated warp knitted PET. Higher treatment discharge current of atmospheric pressure plasma, either O_2 or Air, showed a relatively higher wettability than lower current used, at the same time much lower strength especially when O_2 treated reaching 30% loss, and almost same WVTR.

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References

1. Abidi, N. and Hequet, E. (2004): Cotton fabric copolymerization using microwave plasma, Universal Attenuated Total Reflectance, FITR Study, J. Appl. Polym. Sci., 93, 145 (2004).
2. BS 5445 Method of Test for Wettability of Textile Fabrics.
3. Cheng, C., Zhang, L.Y., and Zhan, R.J.(2006): Surface modification of polymer fiber by the new Atmospheric pressure cold plasma jet, Surface Coating Technology 200,6659-6665.
4. Coates, J. (2000): Interpretation of Infrared Spectra, A practical Approach, Encyclopedia of Analytical Chemistry, Meyers, R.A. (Ed.), PP10815-10837, John Wiley & Sons Ltd, Chichester, Newtown, USA, 2000.
5. Cui, N.Y. and Brown, N.M.D (2002): modification of the surface properties of a polypropylene (PP) film using air dielectric barrier discharge plasma, applied surface science, 189, 31-38.
6. El Zeer, D. and Salem, A.A. (2014): Effect of Atmospheric pressure glow discharge plasma on the surface modification and the printing properties of wool/polyamide blend, international journal of innovation and Applied studies, vol.7 no. 1 2014 pp.159-173.
7. El Zeer, D.M, Salem, A.A., Rashed, U.M., Abd El baset, A. and Ghalab, S. (2014): A comparative study between the filamentary and glow modes of DBD plasma in the treatment of wool fibers, journal of Engineering research and Applications, vol.4, issue 3,2014, pp 401-410.
8. Ferrero, F. (2003): Wettability measurements on plasma treated synthetic fabrics by capillary rise method. Polymer Testing, 22, 571-578.
9. Fourt, L. and Harris, M. (1947): Textile Research Journal, 5: 256-263.
10. Gabr, B.G., Salem, A.A. and Hassen, Y.E. (2010): "Thermo-Physiological Comfort of Printed Coolmax Fabrics", Textile Asia, June, 2010, Volume XLI Number 6, pp 23-28.
11. Holmes, D.A. (2000): "Waterproof Breathable Fabrics", in Horrocks, A.R. and Anand S.C. (eds.) Handbook of Technical Textiles, The Textile Institute, CRC, 1st edition, Wood Head Publishing Limited, England, pp 282-314.
12. Huang, J. (2015): Review of Heat and Water Vapour Transfer through Multilayer Fabrics,Textile Research Journal, May 2015.
13. Hwang Y.J., Mccord M.G., An J.S., Kang B.C., and Park S.W. (2005): Effect of Helium Atmospheric Pressure Plasma Treatment on Low-Stress Mechanical Properties of Polyproplene Nonwoven Fabrics, Tex. Res. J., 75 (11) (2005) 771-778.
14. Jahagirdar, C J and Tiwari, L.B. (2004): A study on plasma polymerization of dichloromethane on cotton and polyester fabrics, J. Appl. Polym. Sci., 94(5), 2014- 2021 (2004).
15. Jahagirdar, C J and Tiwari, L B (2007): Plasma treatment of polyester fabric to impart the water repellence Property, journal of Applied Physics, April 2007, vol 68(4), pp. 623-630.
16. Jasso, M., Hudec, I., Alexy, P., Kovacik, D. and Krump, H. (2006): Grafting of maleic acid on the polyester fibers initiated by plasma at atmospheric pressure, International journal of Adhesion & Adhesives,26,274-284.
17. Kogelschatz U., Eliasson B., and Egli W. (1997): Dielectric-Barrier Discharges, Principle and Applications, J. Physique, IV, 7 (C4), 1997, 47-66.
18. Kogelschatz, U. (2003): Dielectric-Barrier Discharges: Their History, Discharge Physics, and Industrial Applications, Plasma Chemistry and Plasma Processing, 2003, 23(1), 1-46.
19. Lima da Silva, R.C., Alves Jr, C., Nascimento, J.H., Neves, J.R.O. and Teixeira, V. (2012): Surface modification of polyester fabric by non-thermal plasma treatment, Journal of physics: Conference Series 406(2012) 012017.
20. Meichsner, J., Schmidt, M., Schneider, R. and Wagner, H. (2013): "Non-thermal Plasma Chemistry and Physics", edited by CRC Press, 2013.
21. Pappas, D., Bujanda, A., Demaree, J.D., Hirvonen, J.K., Kosik, W. and Jensen, R. (2006): Surface modification of polyamide fibers and films using atmospheric plasmas. Surface Coating Technology, 201, 4384-4388.
22. Poll H.V., Schladitz U. and Schreiter S. (2001): Penetration of Plasma Effects into Textile Structures, Surf. Coat. Technology, 143(1) 489-493.
23. Polyamide Fabrics by Atmospheric Pressure Glow Discharge Plasma, Polymers from Renewable Resources, Vol. 5, No. 3, 2014.
24. Raslan, W.M., Rashed, U.S., El-Sayad, H. and El-Halwagy, A.A. (2011): Ultraviolet Protection, Flame Retardancy and Antibacterial Properties of Treated Polyester Fabric Using Plasma-Nano Technology, Materials Sciences and Applications, 2011, 2, 1432-1442.
25. Ren, Y.J. and Ruckman, J.E. (1999): Effect of condensation on Water Vapour Transfer through waterproof Breathable Fabrics, Journal of Coated Fabrics, vol. 29, No. 1- July 1999, 20-36.
26. Retcl, M. (2008): Surface and coating technology, 202, 3427-49.

27. Ruckman, J.E. (1997): An Analysis of Simultaneous Heat and Water Vapour Transfer through Waterproof Breathable Fabrics, Journal of Coated Fabrics, vol. 26, April 1997, 293-307.
28. Salem, A.A. and Morgan, N.N. (2014): Modification of Polyester and Polyamide Fabrics by Atmospheric Pressure Glow Discharge Plasma, Polymers from renewable resources, vol.5, no.3 ,pp 115-138.
29. Shin, Y., Son, K. and Yoo, D.IL. (2007): Functional finishing by using atmospheric pressure plasma: Grafting of PET nonwoven fabric, Journal of Applied polymer science, 103, 3655-3659.
30. Shishoo, R. (2007): Plasma Technology for Textiles, Chapter 6, Woodhead Publishing Limited, Cambridge, 2007, p. 159
31. Wagner, HE, Brandenburg R, Kozlov KV, Sonnenfeld A, Michel P, Behnke JF. (2003): The barrier discharge: basic properties and applications to surface treatment Vacuum, 2003; 71:417–436.
32. Weiner, L. I. (1970): Textile Chemist and Colourist, 22: 378-385.
33. Yaman, N. (2009): Improvement surface properties of polypropylene and polyester fabrics by glow discharge plasma system under atmospheric condition, Tekstil ve konfeksiyon I.

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