Improve Medical Barrier Fabrics Breathability with Atmospheric Plasma

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Abstract

One of the most demanded properties of barrier fabrics for medical applications is the developments of a low cost non-woven material that is breathable, sterilizable, flexible, and resistant to blood and viral penetration. There are many potential techniques which have been considered to produce such a fabric, such as through increased basis weight, the application of barrier coatings or films, using meltblown and bi-component fibers, and others. However, many of these techniques add substantial cost, rigidity, and decrease the feel and comfort of the fabric. A new technique has been developed which leverages the in-line continuous processing advantages of atmospheric plasma technology to improve nonwoven breathability, as well as improved surface modification results for natural fabric properties such as cotton wax content, abrasion resistance and tensile strength. The Atmospheric Plasma Treatment (APT) process allows treatment using a broad range of reactive gases and has been successfully tested on various nonwoven fabrics. Further, depending upon the magnitude of surface effect required and type of nonwoven material, line speeds in excess of 200 fpm are practical and greater than 500 fpm have been achieved. This presentation will review the latest data regarding the key benefits for applying APT for processing medical fabrics.

Introduction

Breathable fabrics can be broadly classified into groups, including woven fabrics, membranes, micro-porous/hydrophilic membranes, smart breathable fabrics, and biomimetic fabrics. Most woven fabrics are closely woven long staple cotton yarns which are plied to improve regularity and will have a pore size of approximately 60 µm. When the fabric surface is wetted, the cotton fibers will swell in the transverse direction and therefore reducing pore size. These fabrics can also be made from synthetic monofilament yarns, typically 10µm, which will form pore sizes with the same approximate dimension. Membranes are typically constructed from polymeric materials and, although hydrophobic in nature, will allow for the diffusion of water molecules through the structure. Some of these structures incorporate microporous polymeric coatings such as expanded polytetrafluoroethylene to provide both water vapor diffusion as well as water resistance. Micro-porous/hydrophilic membranes are coated with co-polymers with both hydrophilic (water vapor permeation) and hydrophobic (water resistance) segments. These bi-component micro-porous materials will inherently have reduced breathability and greater stiffness. Smart breathable fabrics respond to large variations in temperature over short periods of time using stimuli-sensitive coatings. Phase-change polymers are key to their performance, but challenges remain in terms of maintaining responsive breathability behaviors in these environments. Biomimetic fabrics mimic biological mechanisms to achieve the required function. This fabric technology is still evolving in improving material formulations to enhance the control of pore size, pore distribution, and improved film and coating materials for breathability applications.

Current state breathable, water-resistant medical fabrics are being applied to healthcare products such as cushions for wheel chairs, hospital mattresses, hospital mattress and pillow covers, incontinent pads and pants, and orthopedic braces. These fabrics constructed with monolithic and microporous coatings and by lamination can be manufactured of polyester, polyester/nylon blends. These constructions and can be customized with degrees of stretch, and with performance coatings such as antimicrobial or flame-retardance.

However, the “holy grail” of medical barrier fabrics are low cost nonwoven materials which are not only breathable, but also sterilizable, flexible, and resistant to blood/viral penetration. The simplest method to increase the barrier properties of nonwoven fabrics is to increase its basis weight. In reality, method impacts fabric cost and comfort moreso than barrier. Another method is to incorporate a hydrophobic fiber into the fabric. A similar approach is to coat or bond films to the nonwoven fabric. It is generally recognized, however, that coated fabrics will not breathe since conventional films are not breathable. Yet another approach is to reduce the denier of the fibers used for manufacturing the nonwoven fabric. This will decrease the size of the pores in the fabric (given the same basis weight) and also increase the surface area of the fibers. However, this approach can increase the cost basis for the fabric, and there is an issue with the thermal bonding of these nonwoven constructions because of fiber spinning, carding and webbing complications of low denier fibers. Further, spun/melt/spun (SMS) fabrics have a layer of meltblown fibers encapsulated between two layers of spunbonded polypropylene fabric and can provide an excellent barrier layer while preserving fabric breathable. The major disadvantage to SMS fabrics is the cost of the required processing equipment and the low throughput of meltblown fabrics.

In addition to the need for a more cost-efficient method to impart breathability, the poor dyeability of polypropylene nonwovens has limited optimization of its applications in the manufacturing of medical and industrial fabrics. Fibers with polar functional groups can be dyed more easily than non-polar fibers since polar groups will chemically bond with dye molecules. Because the molecular chains of polypropylene are non-polar and its surface is hydrophobic, the dye molecules will not chemically bond to the fibers. Polypropylene fibers also are highly crystalline, which also restricts its dyeability.

Recently, plasma technology has been shown to improve fiber surface properties such as breathability and dye-uptake without affecting the bulk properties of these fibers. However, low-pressure plasma systems have required expensive vacuum equipment in order to increase surface hydrophilicity, particularly for commercial speed lines. A novel atmospheric plasma treatment (APT) process has been developed using glow discharge (APGD) technology as a result of studying the reaction mechanisms between plasma and fiber surfaces to optimize industrial system applications. The atmospheric plasma treatment apparatus does not require any vacuum systems, produces a high-density plasma, and provides treatment of various textile substrates at low temperature while operating at atmospheric pressure. This system also has the flexibility to be manufactured and used as a reduced ozone corona system. The fiber structure of spunbonded polypropylene materials can be enhanced for improved breathability, and functional groups can be introduced onto the surface of fibers by using gas plasma treatments. By creating a polar layer on the fiber surface in concert with functionality introduced, wettability of the fiber for dyeing is also enhanced. The wettability of various synthetic and natural fibers has been dramatically increased by this process. Electron microscopy has shown that the surface of fibers after atmospheric plasma treatment is uniform and consistent, confirming that the atmospheric plasma surface treatment is homogeneous.

Experimental – Cotton Nonwoven Processability

To evaluate the effect of APT on the raw cotton nonwoven fabrics, a modification to the existing method for the determination of cotton waxes is proposed. Specific to this experimental, Texas cotton was carded and double needlepunched through the Needlepunching Line at a Texas Tech University facility. Two fabrics were produced through the double needlepunching line, each weighing 225 GSM and 125 GSM, respectively.

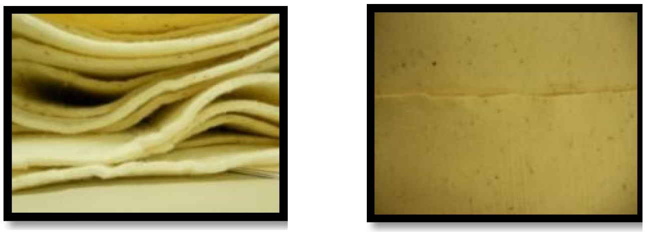


Figure 1. 225 GSM and 125GSM Needlepunched Cotton

2009 Texas Crop					
Mike	Length	Uniformity	Strength	Color	Leaf
4.14	1.05	82.2	27.2	13.3	4-11

Table 1. Texas Cotton Grade Specification

The APT surface treatment was performed at Enercon Industries Corporation on its 1.5 meter wide Plasma3™ system in Wisconsin, USA.

Figure 2. Enercon Plasma3™ Atmospheric Plasma Treatment System

Trial parameters used are tabulated below:

APT Parameters	
Power Applied	4 KW
Gas Used	Oxygen in Nitrogen atmosphere
Ceramic Plasma Electrode Width	559 mm
Speed	20 FPM
Time	30 sec

Table 2. Atmospheric Plasma Surface Modification Parameters

Following plasma surface treatment, a determination of cotton wax content was conducted using a modification to the Accelerated Solvent Extraction (ASE 100) method. Specifically, wax content of the cotton was extracted through the Soxhlet extraction method. The Soxhlet extraction process ensures intimate contact of the sample matrix with the extraction solvent. We have used the ASE to evaluate the cotton wax present in the raw cotton. ASE is the specialized extraction technique which works at elevated temperatures and pressure conditions, enabling highly efficient and rapid extractions of solid and semi-solid sample matrices.

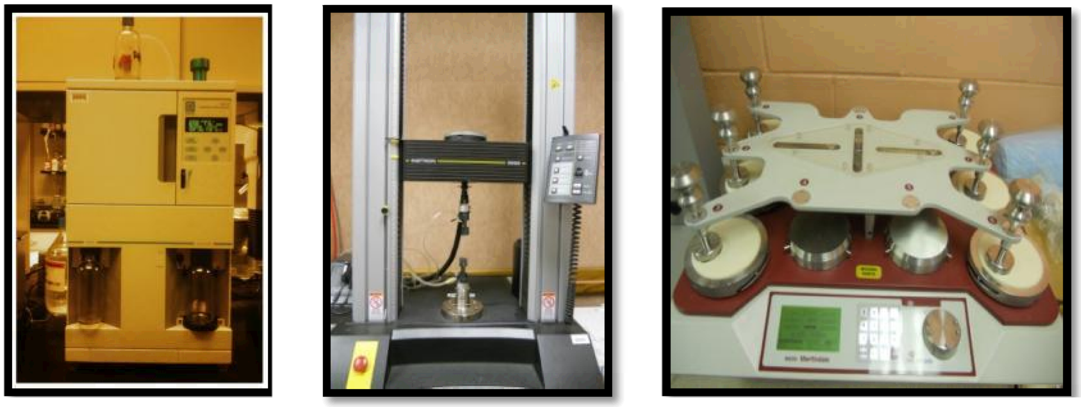


Figure 3. Soxhlet Extraction, Universal Tensile Tester, Martindale Abrasion Tester

Cotton wax content before and after atmospheric plasma treatment was determined, with the mean value of the cotton wax present in the cotton by its weight as 2.15% for untreated cotton, and 1.12% after plasma treatment. The statistical difference was significant enough, at p= 0.002.

Strip tensile test measurements were conducted on each sample by using a Universal Tensile Tester Instron 5569, and by following the ASTM D 5035-06 method. Abrasion testing was conducted using a Martindale Abrasion Testing unit by following the ASTM D 4966 Standard. For tensile strength testing, 2C strip tests were conducted for both the 225 GSM and 125 GSM samples before and after APT under three repetitions. The statistical difference was calculated for load at break (N) values among the different samples.

Sample Type	P-value	Significant Difference
125 GSM CD	0.248	No
125 GSM MD	0.036	Yes (6.3% ↓)
225 GSM CD	0.97	No
225 GSM MD	0.077	No

Table 3. Tensile Strength Testing Results

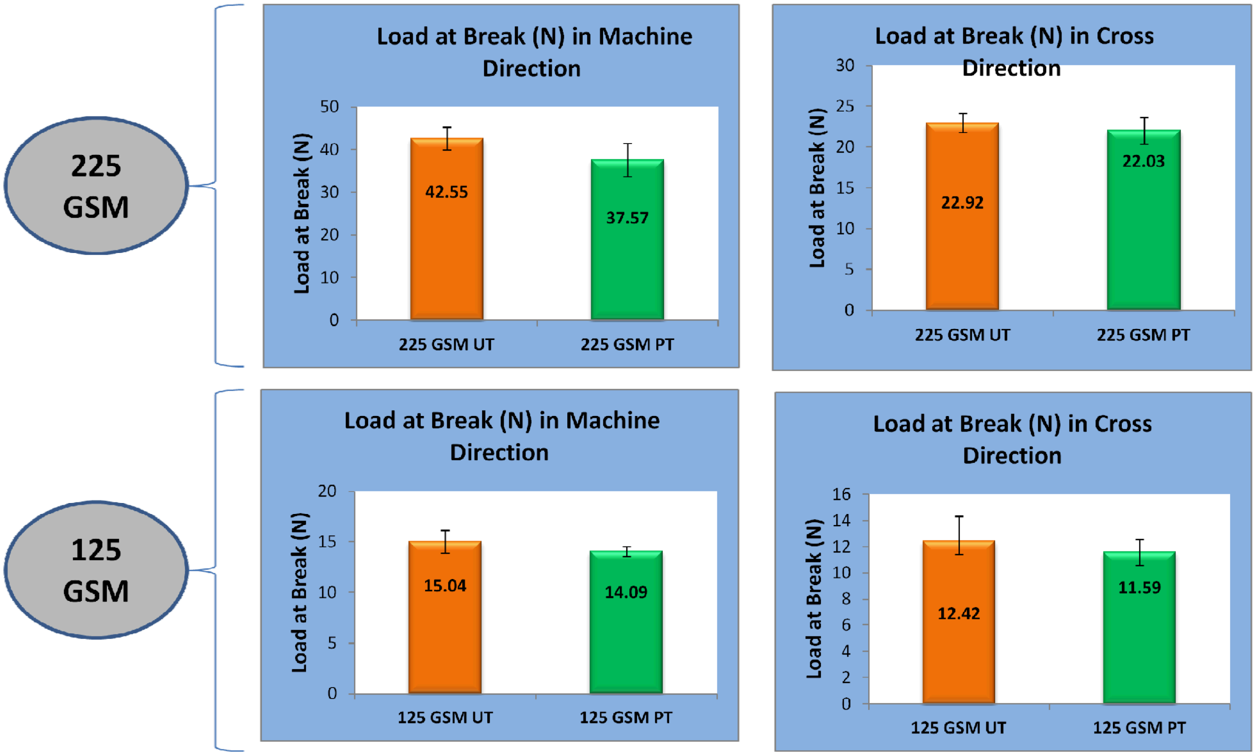
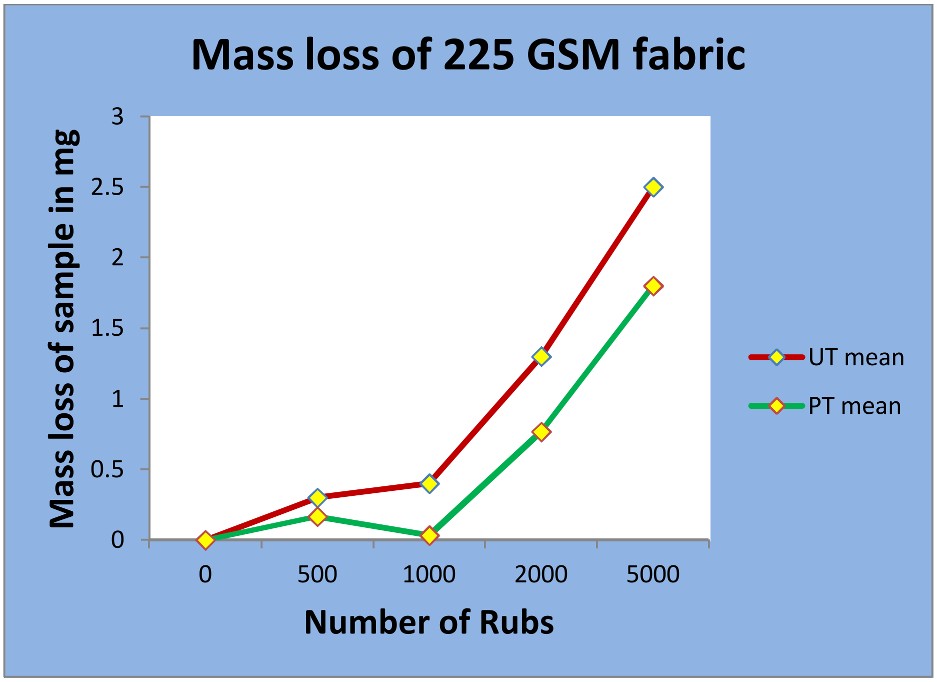


Figure 4. Tensile Strength Comparison by Sample Type

Abrasion tests were conducted under three repetitions as well. The mass loss after 5,000 rubs was discovered to be more with untreated fabrics compared to the plasma treated fabrics. The P-value of sample mass loss after 5,000 rubs were as follows:

- 225 GSM: P-value is 0.08 (no significant change)
- 125 GSM: P-value is 0.44 (no significant change)



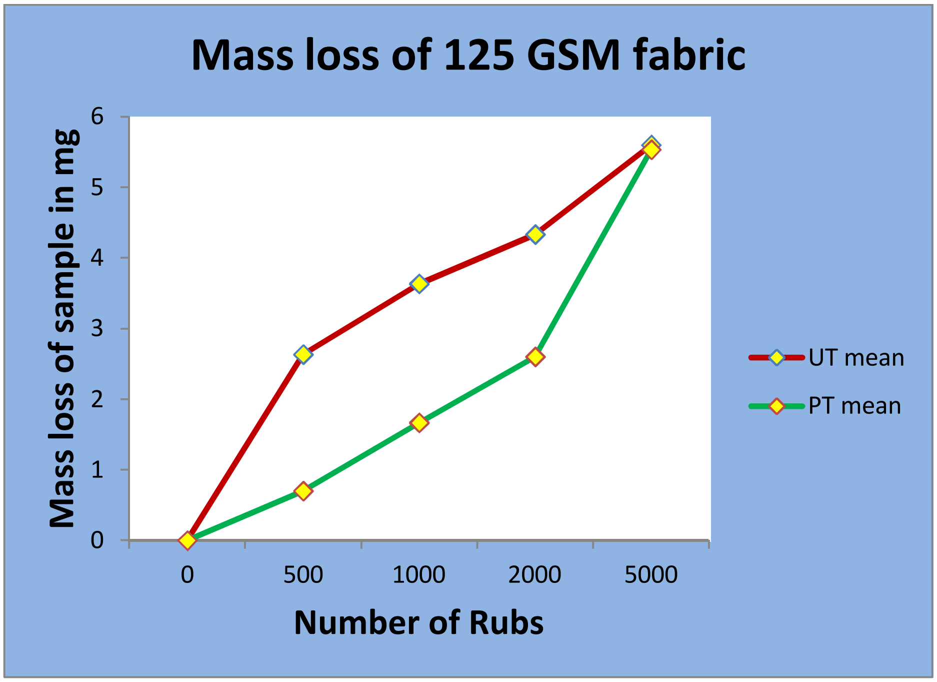


Figure 5. Fabric Mass Loss Following Abrasion Testing for Untreated (UT) and Plasma Treated (PT) Samples.

Experimental – Polypropylene Nonwoven Breathability

Concerning breathability with medical-grade fabrics, results on the enhancement of moisture vapor transport characteristics of polypropylene spunbonded nonwovens via two protocols of atmospheric plasma functionalization were subsequently analyzed. In one protocol, spunbonded nonwoven fabrics were treated in a plasma chamber with oxygen pulled from the atmosphere. In the second protocol, spunbonded nonwovens were treated with nitrogen gas in oxygen atmosphere so that the surface was etched intensively which was theorized to enable greater transport of moisture through the filaments. MVTR was evaluated using the standard method BS7209. Spunbonded samples of three different weights (20, 50, 75 g/m2) respectively) were used in this study to examine the effect of fabric weight on atmospheric plasma functionalization. Breathability evaluations of untreated and plasma treated nonwovens employed the use of a rotating disc MVTR instrument. Breaking strength evaluations followed the ASTM D-5034 method using a Universal Tensile Tester (Instron 5569). Pore size distribution was assessed using a capillary flow porometer at Porous Materials, Inc. The test applied was T-502 - Pore Distribution and Bubble Point.

The atmospheric plasma trial parameters used are tabulated below:

APT Parameters	
Power Applied	4 KW
Gas Used	1) Atmospheric air,
Ceramic Plasma Electrode Width	1524 mm
Speed	50 FPM
Number of Sides Treated	2

Table 4. Atmospheric Plasma Surface Modification Parameters

Vapor transmission rates were conducted by the Evaporative Dish Method (BS 7209:1990). Samples were conditioned at 20°C and 65% relative humidity for 24 hours prior to testing. By procedure, successive weighing of the dish assembly before and after 5 hours yields the amount of water vapor permeated through the fabric. The resultant transmission rates are detailed below:

Plasma Treatment in Oxygen Atmosphere			
Sample Weight (GSM)	MVTR Values		Increase in Breathability (%)
	Untreated	Plasma Treated	
20	707.85	876.39	23.81
50	858.65	1284.42	49.59
75	904.77	1149.59	27.06
Plasma Treatment with Reactive Nitrogen Gas in Oxygen Atmosphere			
20	707.85	1380.22	94.99
50	858.65	1241.85	44.63
75	904.77	1101.69	21.76

Table 5. Chart of MVTR Values Following Evaporative Dish Testing

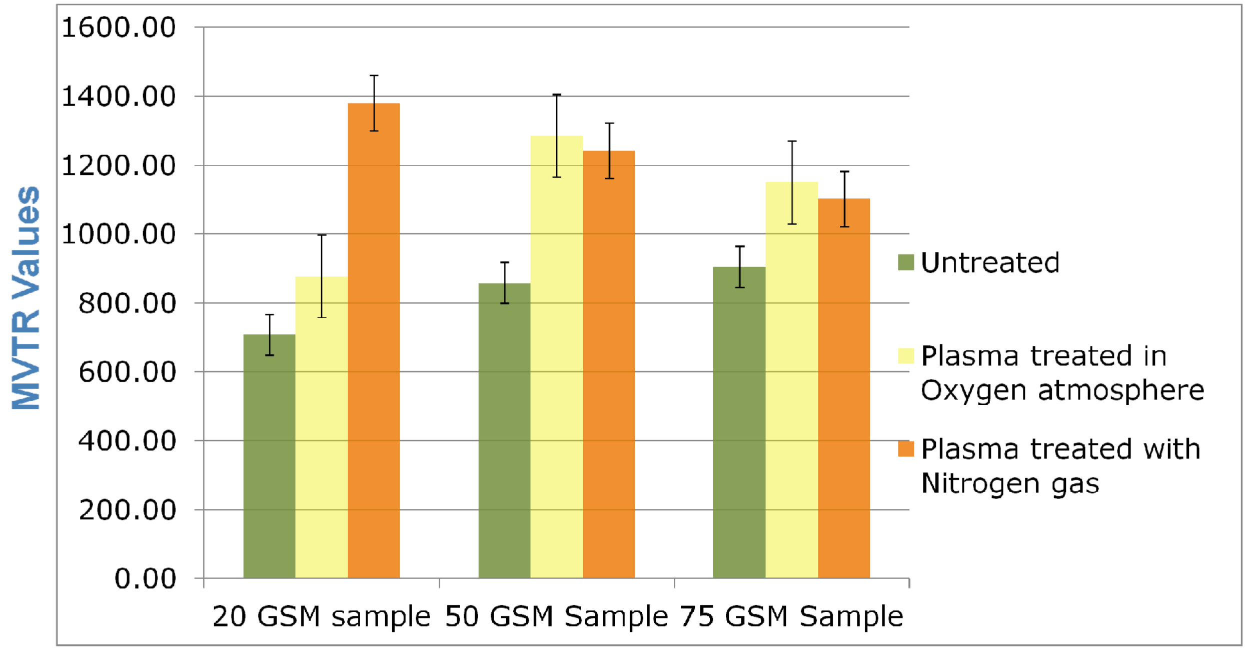
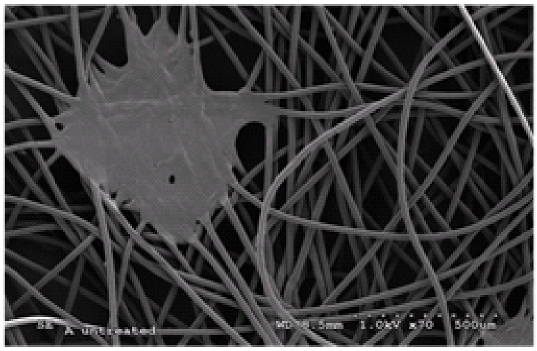
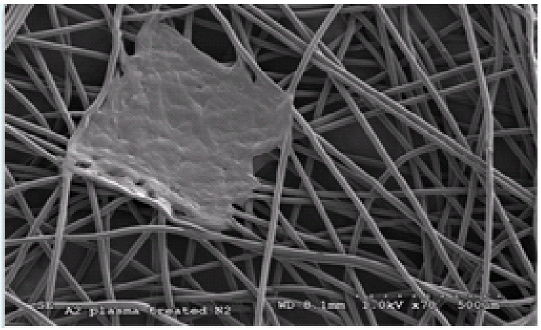


Figure 6. Histogram of MVTR Values Following Evaporative Dish Testing



- Fibers are intact
- Less breathable

Figure 7. SEM Image of Untreated 20GSM Spunbonded Polypropylene Nonwoven



- Fibers get loosened
- Increased pore size between fibers
- Results in enhanced breathability (95%)

Figure 8. SEM Image of 20GSM Spunbonded Polypropylene Nonwoven Plasma Treated in O2 Atmosphere with N2 Gas

Sample	Description	MEAN FLOW PORE DIAMETER (Microns)	
		Mean	SD
UT 1	20 GMS Untreated	59.95	7.31
PT 1	20 GSM Plasma Treated	72.54	11.76
UT 2	75 GSM Untreated	36.83	6.08
PT 2	75 GSM Plasma Treated	33.39	3.96

Table 6. Pore Size Distribution

Conclusions

Results showed that both oxygen and combined gas functionalization resulted in more moisture vapor transport characteristics. In addition, lighter fabrics were more susceptible to atmospheric pressure plasma treatment which is reflected in higher MVTR values.

In a general sense, the MVTR was enhanced by 95% in lightweight fabrics. Statistical analysis showed that the MVTR values of plasma treated fabrics, irrespective of their weights, were significantly different from those of untreated spunbonded structures. This robust analysis provides solid evidence that the atmospheric pressure plasma process in the presence of gases like nitrogen can serve as a viable method to enhance the breathability and cotton-like characteristics of synthetic nonwovens. Conclusions attributable to this full study:

- The APT process can be used to increase the processability of cotton
- Cotton wax evaluation results have proved that APT can decrease the wax content of the raw cotton significantly and making it less hydrophobic
- Tensile strength of the fabrics after plasma treatment has no significant change
- Abrasion resistance increases after the APT
- Atmospheric Pressure Plasma treatment enhances the breathability of PP spunbond nonwovens of smaller GSM by 95%
- AP plasma treatment loosens the structure as evident from SEM images
- Plasma treatment on spunbond nonwovens has a significant effect on pore size and distribution of low GSM fabrics at optimum conditions
- Breathability enhancement by plasma treatment can enable spunbond PP nonwovens to penetrate into *next-to-skin* apparel applications