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Non-thermal plasma treatment for hydrophilicity improvement of grey cotton fabrics

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ABSTRACT

In this paper the hydrophilic improvement of the grey cotton fabric by low pressure dc glow discharge air plasma is investigated. The fabrics were treated for different exposure times, discharge potentials and pressure levels. Effect of plasma treatment on the wettability of the fabric was studied by measuring contact angle and dynamic wicking rate. The surface energy values have been estimated using contact angle measurements and effective mean pore radius of the plasma-treated fabrics were estimated by modified Washburn equation via dynamic wicking technique. Degradation and dyeability of the fabrics were determined by weight loss percentage and computer colour matching procedure. Characterization of the functional changes due to the plasma treatment has been carried out by means of Fourier transform infrared spectroscopy (FTIR–ATR). The surface morphology of the untreated and plasma-treated fabrics were analyzed by scanning electron microscopy (SEM).

1. Introduction

In the past decade, a number of conventional methods were adopted to improve the hydrophilicity of the cotton fabrics (Temmerman and Leys, 2005; Poll et al., 2001; John, 2005). These conventional techniques are inherently costly and environmentally unfriendly. In addition, the conventional process that treats the fabric bulk, may adversely affect the over all product performance. Most of the textile industries are motivated to seek alternative surface engineering processes which could lower the cost, improve life time, quality and performance and also environmentally friendly. The non-thermal plasma treatment was found to be an effective method to improve surface properties without affecting the fabric bulk (Poll et al., 2001; Chaivan et al., 2005; Prabaharan and Carneiro, 2005; Erra et al., 2002; Kan et al., 1998, 2005; Wu et al., 1999; Ghoranneviss et al., 2006; Ortiz-Morales et al., 2003; Yip et al., 2002). In a discharge, free electrons gain more energy from an imposed electric field and lose their energy through collisions with neutral atoms or molecules. The energy transfer to the molecules leads to the formation of a variety of new species such as metastable free radicals, UV-radiations, ions and photons (Prabaharan and Carneiro, 2005; Yashuda et al., 1984; Paul and Schreiber, 1994; Maximov et al., 1997; Ramachandran et al., 2004; Rybkin et al., 1997; Correia et al., 1997; Subedi et al., 2005). Furthermore, the ions, electrons, atoms and radicals are able to interact with the surface of the fabric under exposure. The plasma treatment is controlled by applied potential for gas discharge, nature of the gas, position of the fabric inside plasma and exposure time. The plasma-treated fabric surface showed creation of channels for water penetration and formation of the carboxylic acid groups with in the cuticle layer (Prabaharan and Carneiro, 2005). These physical and chemical changes are responsible for the rapid increase in the water absorbency of cotton materials after plasma treatment. In this paper, we investigate effect of plasma treatment on

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the hydrophilicity of the cotton fabrics through contact angle measurements. Also surface energy of the fabric was estimated for selected exposure times, discharge potentials and base gas pressures. Average pore radius of the plasma-treated fabrics was calculated using modified Lucas Washburn equation. The fabric dyeability was analyzed by computer colour matching system. The untreated and plasma-treated fabrics were characterized by FTIR–ATR spectroscopy and scanning electron microscopy.

Table 1 – Typical operating parameters for plasma processing

Applied discharge potential (*V*)	250–400 V
Pressure (*P*)	0.09–0.3 mbar
Exposure time (τ)	2–10 min
Electrode separation (*d*)	1 cm
Plasma gas	Atmospheric air
Dimension of the fabric	4 cm × 4 cm
Fabric weight	0.235 g

2. Experimental setup and methodology

2.1. *Material*

Commercial medium quality woven grey cotton fabric having 53 ends cm^{-1}, 29 picks cm^{-1} was used for the study. The fabrics were supplied by South India Textile Research Association (SITRA), Coimbatore, India. Before the plasma treatment, the fabrics were desized by 1% of hydrochloric acid (HCL) at a temperature of 50 °C for 1 h followed by washing with distilled water and dried in air. This method is used to remove the sizing material (starch) of the fabric surface and minimize the chance of contamination. Other chemicals: sodium chloride (NaCl), sodium bicarbonate (Na_2CO_3) and hydrochloric acid (HCL) were supplied by Fischer Chemic Ltd., India and the reactive dye (cold brand reactive blue) was supplied by Indian Chemical Industries, India.

2.2. *Non-thermal plasma treatment*

Non-thermal (glow discharge) plasma was generated in a plasma chamber of length 29 cm and internal diameter 10 cm made of glass. A pair of circular electrodes (diameter = 5 cm) with their planes parallel to each other and perpendicular to the axis of the chamber where fixed. They are positioned cylindrically symmetric and capable of axial movement (Fig. 1). The electrodes were connected to high tension dc power supply (2 kV). Atmospheric air was used as the plasma forming gas. Discharge plasma was produced at an evacuated air pressure in the range of 0.09–0.3 mbar. The pressure inside the chamber was measured by a pirani gauge. The dc power is applied between the two electrodes. By proper alignment and positioning of the electrodes and adjusting applied potential, a uniform plasma is generated. The fabric is placed perpendicular to the cylindrical axis between the parallel disc electrodes through a feed through. Plasma electron density and temperature were measured using a Langmuir probe. The probe is made of a tungsten wire (length = 2 cm and diameter = 0.05 cm) encapsulated in a glass sleeve. Electron density was 8.9×10^{13} m^{-3} and temperature was 2.7 eV at a pressure of 0.2 mbar and applied potential of 300 V. The typical operating parameters are shown in Table 1.

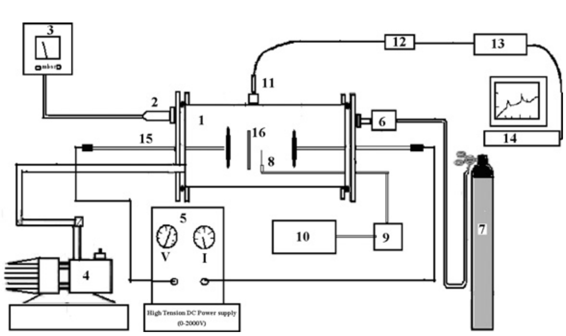

Fig. 1 – Experimental set up of plasma treatment. (1) Vacuum chamber, (2) pirani gauge head, (3) pirani gauge, (4) rotary pump, (5) high tension dc power supply, (6) fine control gas needle valve, (7) plasma gas cylinder, (8) Langmuir probe, (9) commutator, (10) bipolar power supply, (11) fiber optics, (12) 1/4 monochromator, (13) PMT power supply, (14) computer with X_T recorder, (15) electrodes and (16) grey cotton fabric.

3. Method of analysis

3.1. *Contact angle and surface energy estimation*

The wettability of the plasma treated and untreated fabrics were determined by contact angle measurement. The contact angle measurements were carried out at room temperature using a contact angle goniometer (Rame–Hart contact angle goinometer, USA) with drop image standard software of Model 200 using two different test liquids: water and glycerol. The contact angle experiment was carried out using 4 cm × 4 cm of the cotton fabric. Liquid drop of 4 μl was put on the fabric surface and the contact angle was observed after 20 s. The experiment was repeated six times and the average was calculated. The maximum error in the contact angle measurement was ±4%.

Surface energies were estimated using the method of Owens–Wendt; this method takes into account the dispersive and polar components of the surface energy using two different test liquids it is possible to determine the solid surface energy (γ_s) as the sum of the polar (γ_s^p) and dispersive (γ_s^d) contribution (Deshmukh and Bhat, 2003; Bhat et al., 2003; Sanchis et al., 2006). The relationship between the contact angle (θ) of the liquid phase deposited onto a solid phase is derived form the general Fowkes expression which considers the polar and dispersive contributions for both solid and liquid designed as γ_l and γ_s with a superscript "d" or "p" for the dispersive and polar contribution, respectively.

$$\gamma_l(1+\cos\theta) = 2(\gamma_l^d \gamma_s^d)^{1/2} + 2(\gamma_l^p \gamma_s^p)^{1/2} \qquad (1)$$