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ACHIEVING SUSTAINABILITY BY ECO-EFFICIENT PLASMA TREATMENT - A STUDY ON DYEING OF KNITTED MODAL FABRIC

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Abstract

The concept of eco-efficiency provides a structure about breaking the nexus between economic activity and environmental impact in order to achieve sustainable development. It combines the economic welfare and ecological impact of products or service throughout their life cycle. Identifying, researching and adapting most promising alternative solution for textile wet processing is the plasma technology. The research presented in this paper is based on the idea of optimizing the dyeing of argon plasma treated modal knitted fabric. The fabric dye ability measurement was studied by reflectance curves which illustrated the depth of shades of fabrics exposed to 5, 10- and 20-minutes duration. They also resulted in fabrics with better dye-uptake and colour fastness properties. The colour strength values, washing and perspiration fastness properties of dyed fabrics using reactive dyes were excellent. Fresh water depletion and Eco toxicity during dyeing can be effectively controlled by using argon plasma treated modal fabrics. Pollution prevention and resource efficiency can be achieved by critical monitoring through research on plasma treatment as an alternative technology for textile wet processing on advanced cellulosic fabrics.

Key Words: dyeability, eco-efficient, knitted fabrics, modal, plasma treatment, sustainability.

1. INTRODUCTION

The major environmental problems of the textile industry are freshwater resource depletion, as well as human toxicity, aquatic and terrestrial eco-toxicity. The environmental performance of the system is evaluated through the relevant midpoint environmental impact categories, while the economic performance is measured using the total value added to the system's final product due to water and chemical use.

Several studies on plasma treatment have highlighted the environmental benefits. Yip et al. [1] have highlighted on that plasma treatment has an enormous potential as an alternative technology for the textile processing in terms of cost saving, water saving and eco-friendliness. Low temperature low pressure plasma treatment has been shown to be useful and suitable technique to modify a polymer surface, especially natural polymers like cellulose in a dry and pollution free system, as pure water is becoming scarce and expensive. Several surface features such as adsorption, desorption and cross linking occurring owing to air and argon gas plasma treatment on textile materials have been examined by Zhuang et al. [2].

Pretreatment and post treatment possibilities have been attempted by Prabhakaran and Carneiro [3] and have found that if plasma treatment is given before bleaching process, it results in better whiteness, which compares favourably with the conventional method. Also the two-stage process, namely, plasma treatment followed by hydrogen peroxide had led to better dyeability. Sun *et al.* [4] have conducted a very interesting study on the effect of plasma treatment on wool and cotton fabrics. Both untreated and oxygen plasma- treated cotton and wool fabrics were scoured for 25 and 40 minutes. Dyeing was carried out on them using appropriate dyes. Fabric mechanical properties were measured by KES-FB (Kawabata Evaluation System). The low stress mechanical properties of the conventionally scoured and dyed wool and cotton fabrics with their oxygen plasma-treated counterparts for short-term duration times were studied. The research shows that plasma-treatment results in an increase in bending and shear rigidities. An interesting conclusion that emerges out of this study is that no significant difference in fabric total hand value between the plasma-treated wool and cotton fabrics has been noticed. Also, plasma-treated wool and cotton fabrics can be scoured and dyed for shorter periods of time, without affecting the total hand value. Adoption of plasma treatment in the conventional finishing and dyeing processes is thus recommended.

Naebe et al. [5] have investigated the effect of plasma treatment of wool on the uptake of sulfonated dyes with different hydrophobic properties. Their findings are that no significant effects of plasma on the rate dye absorption were observed. The relatively hydrophilic dyes on plasma-treated wool were adsorbed more rapidly and uniformly. They conclude that adsorption of hydrophobic dyes on plasma-treated wool was influenced by hydrophobic interactions, while electrostatic effects predominated for dyes of more hydrophilic character. On heating the dye bath to 90oC in order to achieve fibre penetration, no significant effects of the plasma treatment on the extent of uptake or levelness of a relatively hydrophilic dye was observed, as equilibrium conditions were approached. The dyeing rate, dye bath exhaustion and dyeing uniformity are highly improved by plasma treatment.

2. MATERIALS AND METHODS

2.2 Methods

2.2.1 Experimental Methods

Materials Knitted Single jersey pure modal fabric was constructed using 100% pure modal yarn of 19.68 tex, to study the effect of argon plasma. The geometrical properties are presented in table 1. The developed fabrics were treated using low pressure glow discharge plasma. The glow discharge was generated using an apparatus made by an industry. The DC glow discharge was operated at 0.5 mbar.

Table 1: Table Geometrical properties of untreated and argon plasma treated modal fabrics

Sample	Stitch density (cm^2)	Tightness factor (tex$^{0.5}$ mm^{-1})	Loop shape factor (mm)	Thickness (mm)	Mass per unit area(g/m^2)
Untreated	336	2.02	1.31	0.45	158.67
5 min.	520	3.24	1.3	0.32	153
10 min.	273	1.8	1.14	0.34	144
20 min.	264	1.75	1.17	0.34	144

2.2.2: Dyeing Procedure

Figure 1 gives the dyeing procedure used for the untreated and argon plasma treated modal fabrics.

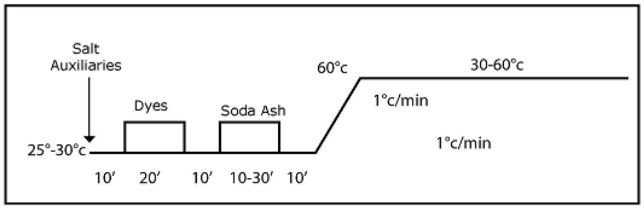

Figure 1: Dyeing profile of fabrics

2.2.2 Analytical Methods

2.2.1 Scanning electron microscopic (SEM) technique: SEM studies were carried out on the samples after mounting them on specimen stubs and coating with AU-PD in a vacuum fine coat ion sputter. For each sample, two specimens were taken. The thickness of the coating and time were optimized before the samples were examined in JOEL SEM model 84 OA .

Measurement of dye exhaustion

The dye exhaustion behavior of the reactive dye on knitted fabrics was investigated. The extent of dye exhaustion for 2% concentration of dye, before and after dyeing was determined using spectroscopic analysis. The analysis was carried out after dilution with distilled water. The wavelength of maximal absorbance was measured for Levofix Red CA at 540 nm.

The dye bath exhaustion percentage (%E) was calculated using Equation (1).

$$\%E = \frac{(A_b - A_a)}{A_b} \times 100 \cdots\cdots\cdots \qquad (1)$$

Where, A_b and A_a are the absorbencies at maximum wavelength (λ max) of dye originally in the dye bath and of the residual dye after dyeing respectively.

Testing of colour strength of dyed samples

The testing of colour performance was measured in terms of reflectance values of the conditioned dyed samples at the maximum wavelength (λ max). Colour strength (K/S) of the dyed samples was calculated using KubelkaMunk Equation (2).

$$K/S = \frac{(1-R)^2}{2R} \quad \text{……………………..(2)}$$

Where R is the reflectance of an infinitely thick layer of material illuminated using D65 illuminant, K is the absorption coefficient, S is the scattering coefficient. The values of R, L, a*, b*, c and h, were measured using Mcbeth color Eye 7000A spectrophotometer.

Testing of Colour Fastness properties

Standard test methods were used to test the colour fastness to washing, rubbing, acidic and alkaline perspiration and light fastness properties of the reactive dyed samples. ISO 105 C06 2010 Test A2S for Washing Fastness, ISO 105-X 12:2001 was followed to test colour fastness to Rubbing Fastness, ISO 105 E04:2008 was followed to test colour fastness to Acidic and Alkaline Perspiration and ISO 105 B02:1994 was followed to test colour fastness to light.

3. RESULT AND DISCUSSION

Figure 2 gives the SEM micrographs of argon plasma treated modal. Argon plasma treated modal show uneven, rough surface with blisters like structures. Figure 2 gives the SEM micrographs of argon plasma treated modal. Argon plasma treated modal show uneven, rough surface with blisters like structures.

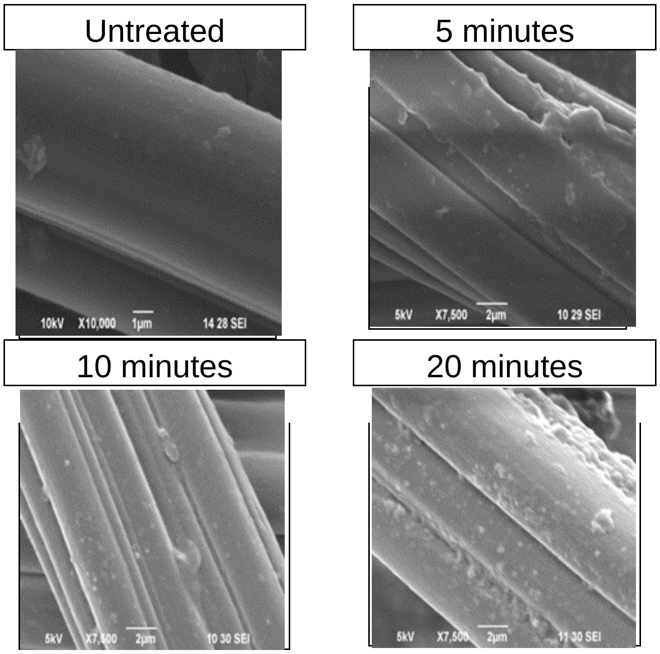

Figure 2: Scanning Electron Micrographs of untreated and argon plasma treated modal Fabric.

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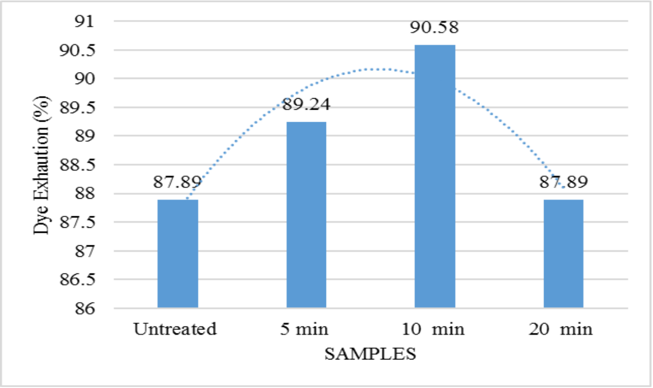

Figure 3: Dye Exhaustion (%) of untreated and argon plasma treated modal fabrics.

Figure 3 indicates that the Dye Exhaustion (%) of argon plasma treated samples has improved as compared to the untreated sample.

Table: 2: Calorimetric values of untreated and Argon plasma treated modal

Samples	L*	a*	b*	c*	h
Untreated modal	45.88	57.9	3.62	58.11	3.57
5 min	39.52	59.29	5.55	59.55	5.35
10 min	39.11	60.57	7.35	61.02	6.92
20 min	41.26	58.94	6.03	59.25	5.84

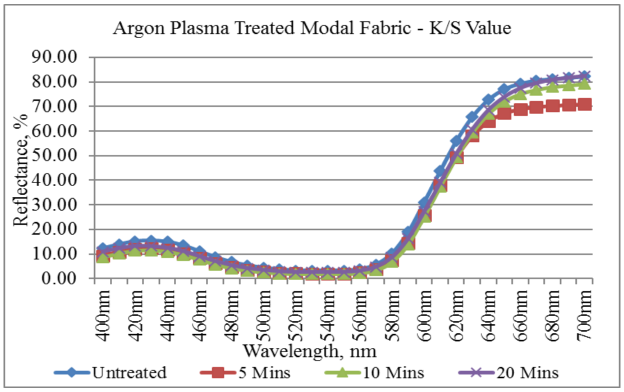

Figure 4: K/S values of untreated and argon plasma treated modal fabrics.

The argon plasma has brought about enhanced colour performance as indicated in figure 4 and 5.

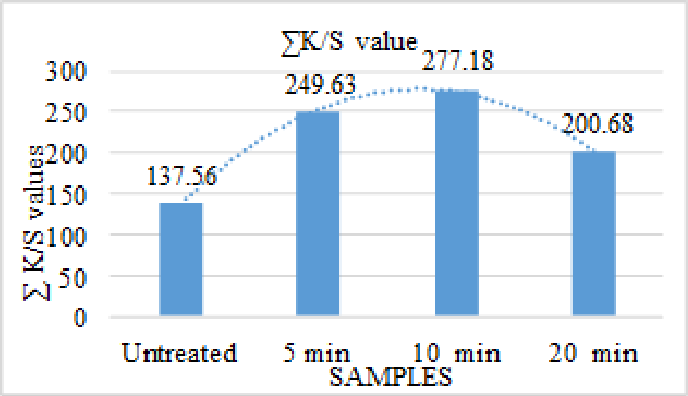

Figure 5: ∑ K/S values of untreated and argon plasma treated modal Fabric.

The fastness values of the argon plasma treated modal clearly indicate that the plasma etching and structural modifications have improved the colour fastness properties.

Table 4 Washing fastness of untreated and argon plasma treated modal

Modal	WASHING FASTNESS						
Sample	COLOUR CHANGE	COLOUR STAINING					
		Acetate	**Cotton**	**Nylon**	**Polyester**	**Acrylic**	**Wool**
Untreated	4	4-5	4	4-5	4-5	4-5	4-5
5 min	4-5	4-5	4-5	4-5	4-5	4-5	4-5
10 min	4-5	4-5	4-5	4-5	4-5	4-5	4-5
20 min	4-5	4-5	4-5	4-5	4-5	4-5	4-5

Table 5: Fastness to acidic perspiration of untreated and argon plasma treated modal

Modal		FASTNESS TO ALKALINE PERSPIRATION					
Samples	COLOUR CHANGE	COLOUR STAINING					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
Untreated	4-5	4-5	3	4-5	4-5	4-5	4-5
5 min	4-5	4-5	4-5	4-5	4-5	4-5	4-5
10 min	4-5	4-5	4-5	4-5	4-5	4-5	4-5
20 min	4-5	4-5	4-5	4-5	4-5	4-5	4-5

Table 5: Fastness to alkaline perspiration of untreated and argon plasma treated modal.

Modal		FASTNESS TO ALKALINE PERSPIRATION					
Samples	COLOUR CHANGE	COLOUR STAINING					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
Untreated	4-5	4-5	3	4-5	4-5	4-5	4-5
5 min	4-5	4-5	4-5	4-5	4-5	4-5	4-5
10 min	4-5	4-5	4-5	4-5	4-5	4-5	4-5
20 min	4-5	4-5	4-5	4-5	4-5	4-5	4-5

Table 6: Rubbing and light fastness of argon plasma treated modal fabric.

Modal	**RUBBING**		**LIGHT**
Sample	COLOUR STAINING		COLOUR CHANGE
	Dry	Wet	
Untreated	4-5	3-4	4
5 min	4-5	4	4
10 min	4-5	4	4
20 min	4-5	4	4

4. SUMMARY AND CONCLUSION

Plasma treatment leads to better dye uptake and eco-friendly environment. The results on argon plasma treated modal fabrics indicate that the objectives of eco-efficiency with respect to optimum usage of water and dye can be effectively accomplished by using this process without compromising on the fastness properties. Plasma treatment can be further used to impart functional properties which include antimicrobial, soil repellency, stain resistance, soft handle and improved dyeing.

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