

# Improving the dyeability of polyester fibre with basic dye using corona discharge accompanied by nanoclay treatment

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This study presents a novel method for dyeing polyester fabric with basic dyes using corona discharge accompanied by nanoclay treatment. Thus, the fabric is treated with corona discharge irradiation at 5 kV and 10 kV for 10 min, followed by treatment with nanoclay at different concentrations. The basic dye absorption behaviour of treated fabric is studied by evaluated using reflectance spectra, colour parameters, and washing and rubbing fastness tests. Response surface methodology analyses indicates that the colour strength of the dyed sample increased while Lightness ( $L^*$ ) decreased with increasing voltage, time and amount of nanoclay. The results suggest that the combined treatment significantly improves the dyeability of polyester fabrics with basic dyes without the need for harsh chemical processes. This method offers alternative for polyester dyeing on commercial scale with less pollution.

**Keywords:** Basic dyes, Corona, Dyeing, Nanoclay, Response surface methodology

## 1 Introduction

Polyester is one of the most important man-made fibres with special properties. This fibre is very resilient, quick drying, resistant to biological damage such as mould and mildew, easy to wash, and able to hold forms well<sup>1</sup>. Polyester belongs to a category containing the esterfunctional group in their main chain. Most synthetic polyesters are not biodegradable<sup>2</sup>. Depending on the chemical structure, polyesters can be thermoplastic or thermoset; however, the most common polyesters are thermoplastic. Polyester clothing tends to be slippery and silky in feel, although it can cause skin irritation for some wearers. Some polyesters are blended with other fibres to provide more stretch or to minimise skin irritation. But one of the essential properties of clothes is their colour. In the textile industry, polyester encompasses several serious problems in garment production due to nonpolar groups on the fibre surface. One of them is that polyester can only be dyed with disperse dye under high temperature (around 130 °C) and high pressure, this needs a lot of energy and special equipment<sup>3</sup>.

There are some methods to improve the wettability and dyeing properties of polyester. Some of these

methods are chemical that occur in an aqueous environment, like alkalising the polyester fabric, but pose significant problems such as the pollution of the wastewater and producing excess heat. However, some methods, such as plasma finishing, do not need the aqueous condition to affect the polyester. The textile's pre-treatment and finishing by non-thermal plasma technologies are becoming increasingly popular as a surface modification technique. It offers numerous advantages over the conventional chemical processes. Plasma surface modification does not require water and chemicals, resulting in a more economical and ecological process. The enormous advantages of plasma processes concern the drastic reduction in pollutants and a corresponding cost reduction for effluent treatment. A non-thermal or low-temperature plasma is a partially ionised gas with electron temperatures much higher than ion temperatures. The high-energy electrons and low-energy molecular species can initiate reactions in the plasma volume without excessive heat causing substrate degradation. Non-thermal plasmas are particularly suited for textile processing because most textile materials are heat-sensitive polymers. In addition, it is a versatile technique where a large variety of chemically active functional groups can be incorporated into the textile surface. This aims to improve wettability, adhesion of nanoclay treatment,

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printability, induced hydro-and/or oleophobic properties, changing physical and/or electrical properties, cleaning or disinfection of fibre surfaces, etc. Moreover, non-thermal plasma surface modifications can be achieved over large textile areas. Surface modifications using radiation treatments (corona discharge and low-pressure plasma) are adequate methods to improve the wettability of polyester fabric. Corona discharge has been proven to be a useful method for improving the hydrophilic properties of polyester polymer. The treatment can improve the surface affinity and the sticking strength with some hydrophilic polymers because the treatment can lead to the increase of the high reactive free radical oxygen in the polymer surface<sup>4-12</sup>.

The commercial and suitable dye for polyester fibre dyeing is disperse dyes. For polyester dyeing with other dyes, except disperse dye, the plasma treatment is not enough, so material is required to make the connection between the created functional groups by Corona treatment on the surface of polyester and the adhesion of the dye. Modified nanoclay (layered silicate) is one of the newest materials under investigation in the nano dimension in recent years. Montmorillonite, hectorite, and saponite are the most commonly used layered silicates. Layered silicates have two types of structure: tetrahedral-substituted and octahedral-substituted. In the case of tetrahedrally substituted layered silicates, the negative charge is located on the surface of silicate layers, and hence, the polymer matrices can interact more readily with these than with octahedrally-substituted material. Smectite clays (e.g., Na<sup>+</sup>-montmorillonite, Na<sup>+</sup>-MMT) have been a popular layered material for the preparation of polymer-clay nanocomposite materials in the past decade because of their small particles and simplicity of intercalation. The Na<sup>+</sup>-MMT, whose lamella is constructed from an octahedral alumina sheet sandwiched between two tetrahedral silica sheets, exhibits a net negative charge on the surface of layers. Cations such as Na<sup>+</sup> and Ca<sup>2+</sup> are absorbed on the surface to compensate for the net negative charge. Currently, organophilically charged clay layers exchanged by cationic surfactants play an important role in intercalation<sup>13-16</sup>. Vitor and João used the corona discharge technique to change the surface of polypropylene and polyester monofilaments. The obtained results indicated that corona treatment effectively improves the wettability of filaments by oxidation and surface morphology change<sup>17</sup>.

Nourbakhsh<sup>18</sup> used corona discharge pre-treatment and post-treatment to improve the performance of cotton fabric treated with copper and zinc oxide nanoparticles. The results indicate that the absorption and self-cleaning effect and antibacterial performance of treated cotton fabric were increased by corona discharge<sup>18</sup>. GÖCEK developed functionalised nanocomposite fabric by treating the surface of cotton fabric with nanoclay nanoparticles. The obtained result indicated that the durability against washing, tensile strength, flame retardant property and thermal stability increased by treating with nanoclay<sup>19</sup>. Haji *et al.*<sup>20</sup> used the plasma treatment to improve the dyeability of coated polypropylene fibre with nanoclay. The result indicated that the oxygen plasma treatment changed the surface chemistry and morphology of the polypropylene fibre. Also, the plasma treatment improved the dyeability of the polypropylene/nanoclay composite<sup>20</sup>. In a review paper, Moges *et al.*<sup>21</sup> discussed various dyeing and finishing methods for polyester fibres. They concluded that there is a noticeable gap in research concerning the dyeing of polyester with basic dyes. In this context, the present study aims to improve the dyeability of polyester fabric with a basic dye using corona treatment accompanied by applying nanoclay. The corona treatment affects the chemical activity and physical changes on the surface of polyester. The nanoclay changes the polarity of polyester, which improves basic dye absorption behaviour.

## 2 Materials and Methods

The polyester fabric was provided by Giltaft Khazar Co., its weight was 133.3 g/m<sup>2</sup>, di-methyl formaldehyde (DMF) and ethyl alcohol were prepared from Merc Co. A basic dye with trade name AllacrylG. yellow X-GL 400% was provided from Allacryl Co. Retarder with trade name Dyetarder was purchased. The organically modified montmorillonite, Cloisite 30B (Cl30B), was obtained from Southern Clay Products, Inc. It was prepared by the ion exchange reaction between natural montmorillonite and methyl, tallow, bis-2-hydroxyethyl, quaternary ammonium salt.

### 2.1 Corona Discharge Treatment

The polyester fabric was thoroughly washed with detergent and distilled water. Then, the washed fabric was dried in an oven at 85 °C. The fabric was treated by the corona discharge irradiation at different treatment times and voltages. The corona discharge

machine consists of two electrodes connected to high voltages with 5 kV and 10 kV, and the power of the corona device was 1000W. The distance between electrodes and the velocity were set at 3 mm and 2 m/min, respectively.

### 2.2 Treatment of Corona-treated Fabric

The corona-treated fabric was treated with nanoclay. For this purpose, DMF was used as media to transport the clay nanoparticles to the created sites on the surface of corona-treated polyester fabric. Thus, the nanoclay/DMF suspension was prepared at 1 % and 3 % of nanoclay. The treatment was done by immersing samples in nanoclay/DMF suspension solution and squeezing them with two roll pads.

### 2.3 Dyeing of Treated Fabric

The dye absorption behaviour of raw and modified polyester fabric was studied by dyeing with Basic. The polyester fabric was dyed with 1% Basic yellow X-GL 400% dye at an L: R ratio of 1:50, and pH=4. The dyebath temperature was increased from 40 °C to boiling point at a rate of 3 °C/min and retained at the boil for 60 min. The dyed samples were thoroughly washed with distilled water and detergent, rinsed with warm and cold water, and dried.

### 2.4 Study of Colour Parameters and Fastness Properties of the Dyed Samples

The colour and fastness properties of dyed samples were evaluated by measuring reflectance spectra, colour parameters, rubbing fastness, and laundering fastness. The colour parameter and reflectance spectra of fabric were measured by the Colour eye 7000A spectrophotometer of X-rite Company. The Rubbing fastness test was done using the standard AATCC 8 and ISO X12 methods. The rubbing fastness was measured by Crockmeter m238B SDL.

### 2.5 Drop Absorption Test

This test with standard number ASTM D5276-98 (2009) is designed to measure the absorbance affinity of fabric surfaces to a liquid such as water. The fabric was dropped with distilled water by a dropper from a 3 cm distance from the fabric surface in a vertical style. To indicate the affinity of water to the fabric surface, the time of disappearance of the drop was measured. Whatever the estimated time was less, the absorbance was better. The better absorbance shows some chemical and physical modifications that occur on the surface of the polyester fabric.

## 3 Results and Discussion

In this work, the corona discharge technique is used to improve polyester fibre surface hydrophilic properties. The relationship between the corona discharge treatment condition and the water absorbance property of a polyester fabric is shown in Table 1. As shown in this table, the time of water absorption decreases with the increase in discharge voltage. Also, the time of water absorption decreases with the increasing time of corona treatment. The best hydrophilic property as water absorbance is obtained by 70 kV voltage at 10 min.

The effect of corona discharge treatment on the surface of polyester fibre is studied by Scanning Electron Microscopy (SEM). SEM images of untreated polyester treated at 10kV -175s, 10kV-75s, and 5kV-25s are shown in Fig. 1. As shown in this figure, the corona treatment changes the surface of polyester fibre. The surface changes at maximum power and time of treatment (b) are more monotonic than the two other conditions. This is due to the high discharge threads between the two electrodes, and vice versa. The less voltage, the less effect. These images confirm the result of the drop test. This surface modification caused the hydrophilic properties and the water absorption of polyester fabric.

DMF is used as a solvent to prepare the suspension of modified nanoclay for treating the polyester fabric. The DMF/nanoclay suspension solution is prepared in 1, 3, and 5 % (w/w) concentrations. The uniformity of nanoclay treatment is studied using SEM (Fig. 2). As shown in this figure, the corona treatment has two effects on the polyester surface. Firstly, the Corona discharge treatment produces a nano crack in the fabric. Secondly, the corona treatment produced the active group, such as the carboxyl group, on the polyester surface.

The dyeing behaviour of samples is studied by analysing the reflectance spectra and colour

Table 1 — Drop test results

Corona discharge treatment		Time of water absorption, s
Time, s	Voltage, kV	
0	0	13.1
25	5	4.4
75	5	3.56
125	5	3.1
175	5	2.5
25	10	4.2
75	10	3.2
125	10	2.5
175	10	1.7

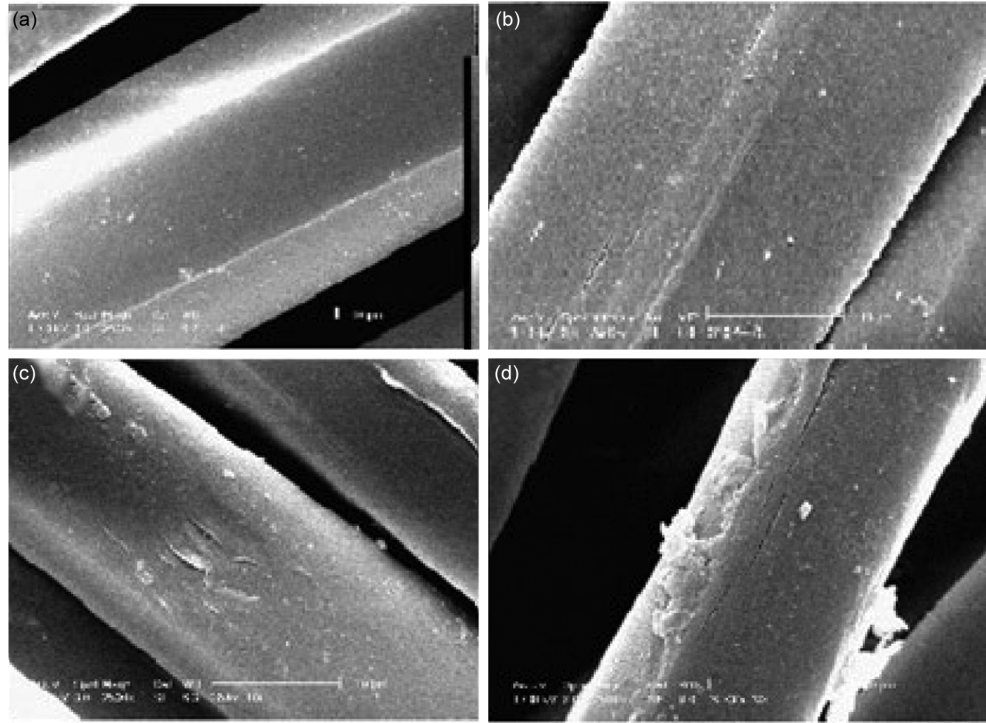


Fig. 1 — SEM images of polyester (a) untreated, (b) treated at 10kV-175s, (c) 10kV-75s and (d) 5kV-25s

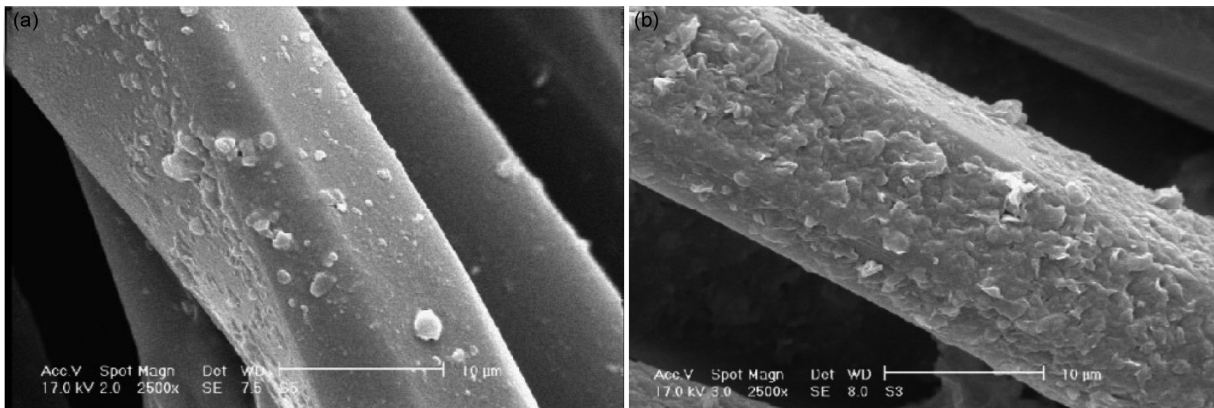


Fig. 2 — SEM images of (a) nanoclay-treated raw polyester, and (b) nanoclay & corona discharge treated polyester

parameters of the dyed sample (Fig. 3). As shown in this figure, the dye absorption of raw polyester is zero. However, the dye absorption of corona-treated and nanoclay-treated polyester fabric is significant. So, the colour depth increased with increasing nanoclay concentration. The colour strength as reflectance function (K/S) and CIELAB colour parameters such as  $L^*$ ,  $a^*$ ,  $b^*$ ,  $C^*$ , and  $h$  are shown in Table 2. This table shows that the lightness ( $L^*$ ) decreased with increasing the nanoclay concentration from 1 to 3 percent.

The dye absorption behaviour is analysed by evaluating the fastness properties of dye on polyester

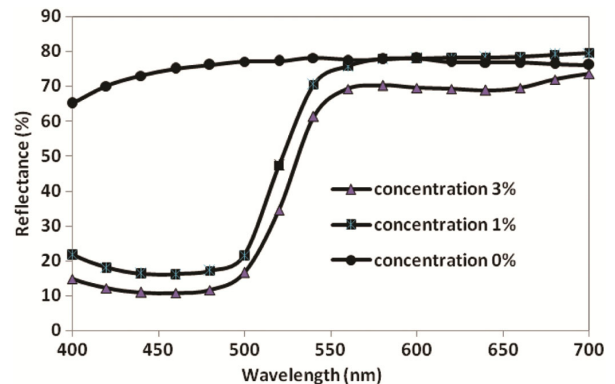


Fig. 3 — Reflectance spectra of raw, corona-treated, and nanoclay-treated polyesters dyed with basic dye

Table 2 — Colour parameter and colour strength (K/S) of dyed samples

No.	Nanoclay conc.	Voltage, kV	Time, s	Colour parameter					Colour strength, K/S
				L*	a*	b*	C*	h	
1	1	0	0	81.79	1.4	52.68	52.7	88.48	29.54
2	1	5	25	81.77	2.94	56.16	56.23	87.01	30.12
3	1	10	75	80.05	2.48	56.52	56.57	87.49	30.96
4	1	10	175	79.98	2.71	58.81	56.87	87.27	30.96
5	3	0	0	81.16	5.18	61.62	61.84	85.19	29.73
6	3	5	25	79.66	6.76	66.56	66.9	84.2	30.46
7	3	10	75	79.89	6.85	63.72	64.08	83.87	30.82
8	3	10	175	78.44	6.61	64.2	64.54	84.12	31.03

Table 3 — Fastness property of dyed fabric

No.	Nanoclay conc.	Voltage, kV	Time, s	Washing fastness	Rubbing fastness	
					Wet	Dry
1	3	5	25	5	3/4	4
2	3	10	75	5	3/4	4/5
3	3	10	175	5	4	4/5

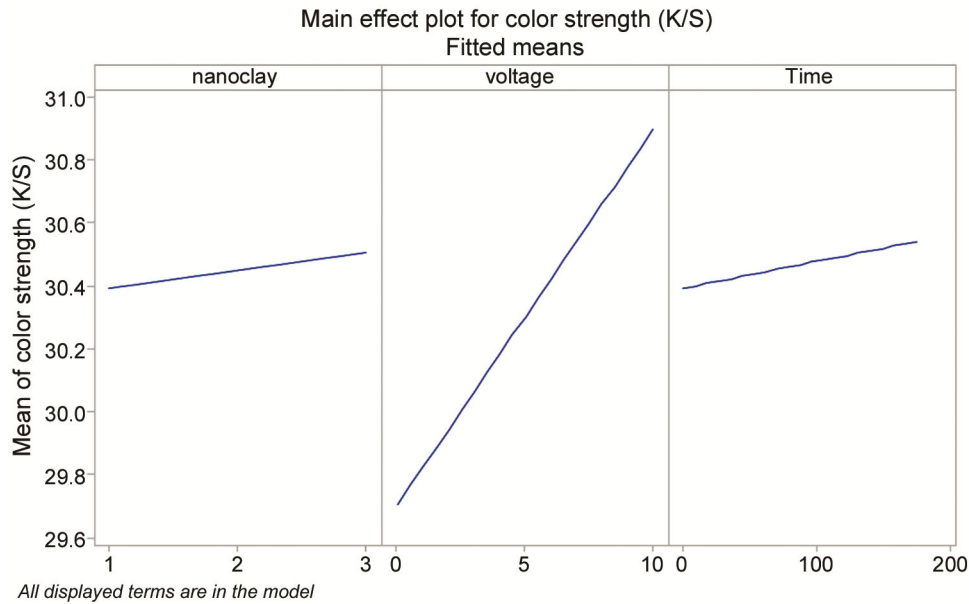


Fig. 4 — Plot of voltage, time and amount of nanoclay on the colour strength (K/S) of dyed samples

fabric (Table 3). The data reveals that the fastness properties of dyed samples are good.

The relationship between the parameters of corona discharge technique, such as voltage, time, and the amount of nanoclay and dyeability of polyester fibre is determined by using the response surface methodology (RSM). The main effects of voltage, time and amount of nanoclay on the colour strength (K/S) are shown in Figure 4. It demonstrates that the colour strength (K/S) is increased with increasing voltage, time and amount of nanoclay, respectively.

The two-factor interactive effect of voltage, time and amount of nanoclay on the colour strength (K/S)

of dyed samples are shown by the response surface two-D contour plot. As shown in Figure 5, there isn't any two-factor interaction between voltage, time and amount of nanoclay.

Also, the main effect of voltage, time and amount of nanoclay on the lightness (L\*) of dyed sample are shown in Figure 6. The lightness (L\*) decreases with increasing voltage, time, and amount of nanoclay, respectively. Also, the two-factor interactive effect of voltage, time and amount of nanoclay on the lightness (L\*) of dyed samples are shown by the response contour plot, indicating there isn't any interaction between voltage, time and amount of nanoclay (Fig. 7).

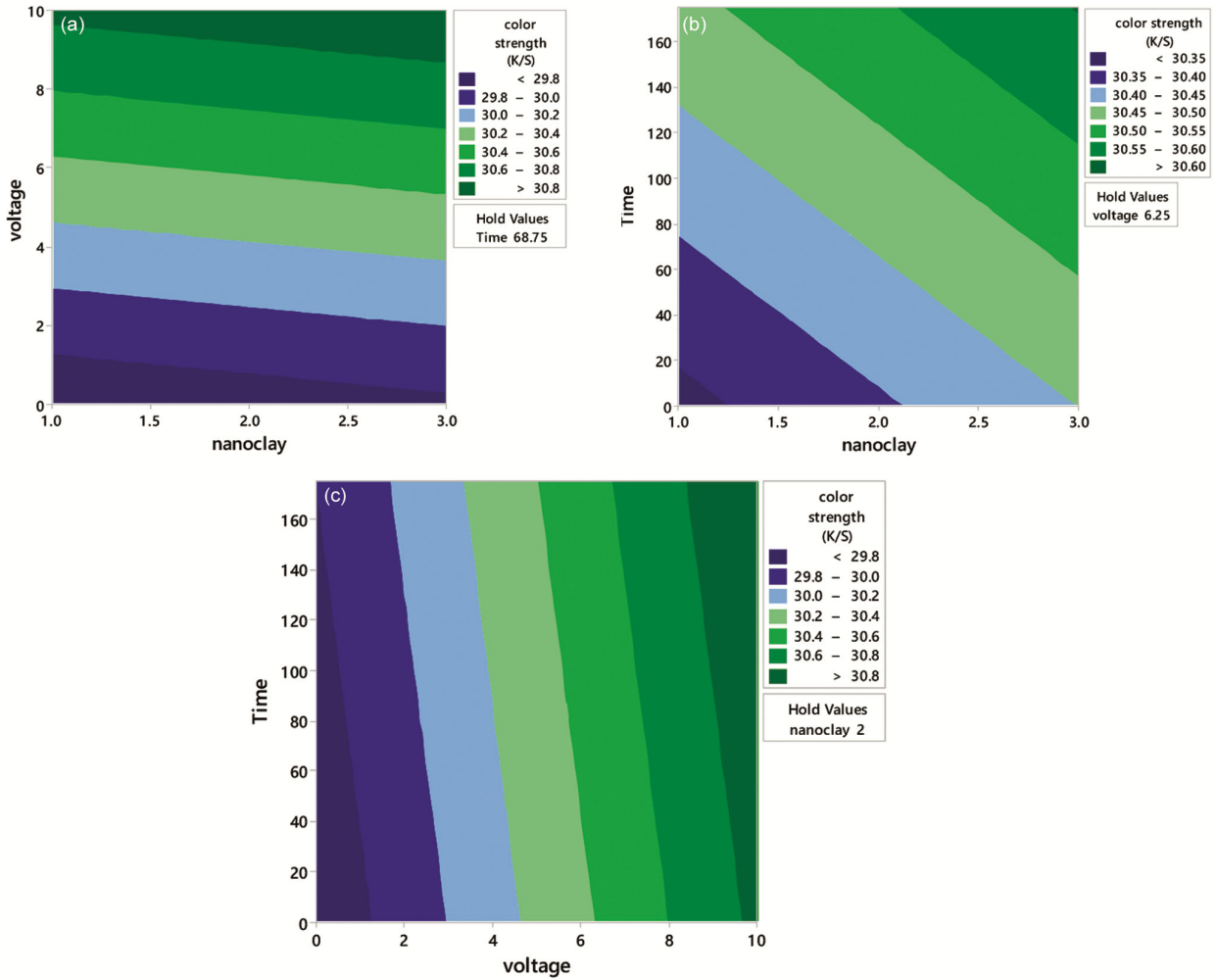


Fig. 5 — Contour plots of the colour strength (K/S) as a function of (a) voltage and nanoclay, (b) time and nanoclay and (c) time and voltage

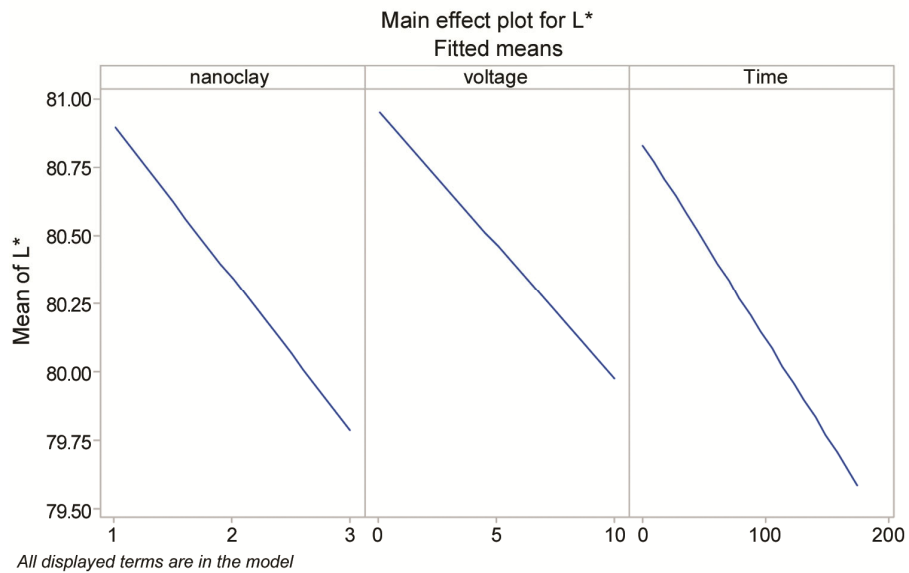


Fig. 6 — Plots of voltage, time and amount of nanoclay on the lightness ( $L^*$ ) of dyed samples

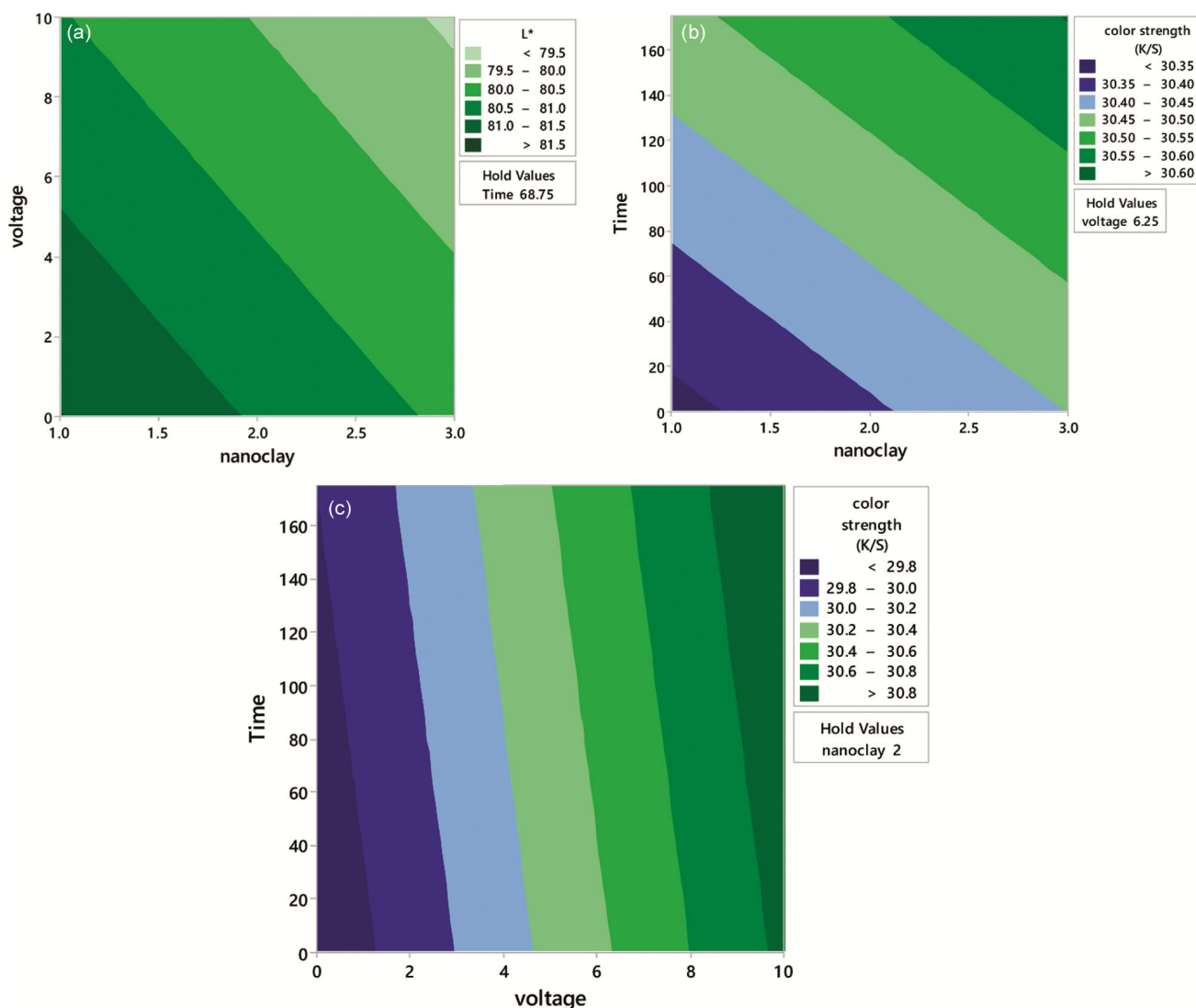


Fig. 7— Contour plots of the colour lightness ( $L^*$ ) as a function of (a) voltage and nanoclay, (b) time and nanoclay and (c) time and voltage

#### 4 Conclusion

In this work, the dye absorption behaviour of polyester fabric with basic dyes is improved by using Corona discharge irradiation and nanoclay. During the Corona treatment, the best hydrophilic property was obtained using a voltage of 10 kV and a time of 175 s. The treatment of Corona-treated polyester fabric with modified nanoclay increases the dyeability of the modified polyester fabric with basic dyes. The dyeing of the modified polyester fabric is successful. The new method of polyester fabric dyeing is environmentally friendly, leaving less pollution than conventional polyester dyeing with disperse dyes. RSM indicates that the colour strength decreased and Lightness ( $L^*$ ) decreased with

increasing voltage, time and amount of nanoclay. Also, there isn't an interaction between voltage, time and amount of nanoclay.

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