DYEING OF POLYESTER KNITTED FABRIC WITH DISPERSE DYES IN ONE-COMPONENT, TWO-COMPONENT AND THREE COMPONENT SYSTEM

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Abstract: *In this study, the dyeing of polyester knitted fabric in one-component – red dye, two-component - red + yellow dye and three-component dyeing system - red + yellow + blue dye was investigated. Polyester is one of the most commonly used synthetic fibers. It has a hydrophobic nature and excellent mechanical properties such as tensile strength and excellent wear resistance. These fibers are usually dyed with disperse dyes that are poorly soluble in water and it is necessary to add auxiliary agents for better solubility. In the experimental part, 100% polyester knitted fabric was used, which was dyed with one, a mixture of two and a mixture of three disperse dyes with the addition of acetic acid and a dispersing agent. The dyeing time was 60 min, while the dyeing temperature was 135 °C. The bath ratio was 1:20. The dye concentrations were 1 and 4%. The dyeing efficiency was analyzed through the K/S values and CIELab parameters. Based on the obtained results, sample dyed with 4% dye in the three-component dyeing system has the highest K/S value.*

Keywords: polyester, knitwear, dyeing, disperse dyes.

BOJENJE POLIESTARSKE PLETENINE DISPERZNIM BOJAMA U JEDNOKOMPONENTNOM, DVOKOMPONENTNOM I TROKOMPONENTNOM SISTEMU

Apstrakt: *U ovoj studiji analizirano je bojenje poliestarske pletenine u jednokomponentnom – crvena boja, dvokomponentnom – crvena + žuta boja i trokomponentnom sistemu bojenja – crvena + žuta + plava boja. Poliestar je jedno od najčešće korišćenih sintetičkih vlakana. Ima hidrofobnu prirodu i odlična mehanička svojstva kao što su prekidna sila i otpornost na habanje. Ova vlakna se obično boje disperznim bojama koje su slabo rastvorljive u vodi i potrebno je dodati pomoćna sredstva za njihovu bolju rastvorljivost. U eksperimentalnom delu korišćena je 100% polistarska pletenina, koja je bojena jednom, mešavinom dve i mešavinom tri disperzne boje uz dodatak sirćetne kiseline i pomoćnih sredstava. Vreme bojenja je bilo 60 minuta, dok je temperatura bojenja bila 135 °C. Razmera banje je bila 1:20. Koncentracije boje su bile 1 i 4%. Efikasnost bojenja je analizirana kroz K/S vrednosti i CIELab parametre. Na osnovu dobijenih rezultata, uzorak tkanine obojen sa 4% boje u trokomponentnom sistemu bojenja boje ima najveću K/S vrednost.*

Ključne reči: poliestar, pletenina, bojenje, disperzne boje.

1. INTRODUCTION

Polyester is one of the most famous synthetic fibers. It is a polymer that contains an ester functional group on the polymer chain. In addition to cotton, with which it is often used in a mixture, polyester makes up about 75% of the produced synthetic fibers in the world [1-3].

Polyester fibers are highly crystalline, thermoplastic with low moisture absorption (absorb only about 0.4% moisture) and excellent wear resistance. It has high tensile strength and chemical stability, which allows it to be used not only for clothing, but also for industrial purposes and as a sailing fabric [4-7].

This fiber is hydrophobic and as a consequence, has a low affinity for large ionic dyes because they cannot form intermolecular interactions. Therefore, direct and reactive dyes are not used for polyester dyeing [8, 9].

Disperse dyes are most often used for dyeing polyester and related fibers. Disperse dyes are a class of small polar molecules and do not contain water-soluble groups and often exist as prepolymers showing nonionic properties with extremely low water solubility [10, 11].

Despite their poor solubility, they can interact with polyester chains by forming dispersed particles. For dyeing polyester and other fibers, dyes must be uniformly dispersed in suspension by adding auxiliaries such as carriers and dispersants [12-15].

The influence of the carrier on the speed of dyeing also depends on the structure of the dye. Carriers have at least one aromatic ring including aromatic hydrocarbons, phenols, ethers and chlorinated aromatics [16].

Adsorption and diffusion of disperse dyes on polyester mostly depends on temperature. Polyester is dyed with disperse dyes at a temperature of 120-130 °C and thermal agitation causes the structure of the polyester to swell and become less crystalline and allows molecules to penetrate the fiber by means of van der Waaslow and dipole forces. The higher the temperature, the higher the mobility of polymer chains in amorphous regions [17-19].

This study presents the process of dyeing polyester knitted fabric in a one-component - one dye, two-component - mixture of two dye and three-component system of a mixture of three disperse dyes from the same manufacturer: Disperse Red 60, Disperse Yellow 211 and Disperse Blue 337. The aim of this study was to investigate the influence of dyeign system (one-component, two-component and three-component systems) and dye concentration on the intensity of dyeing and colorimetric characteristics of polyester knittied fabric. By analyzing the reflectance and determining the CIELab coordinates, as well as the K/S values, it is possible to compare the achieved saturation, hue and chromaticity of the samples dyed in different systems and under different dye concentrations.

2. EXPERIMENTAL

2.1 Materials

In experimental part, a polyester knitted fabric called INTERLOK 100% PES, manufactured by Nitex (Niš, Serbia), was used.

2.1.1 Dyes

Three different disperse dyes were used: a) Disperse Yellow 211, b) Disperse Blue 377 and c) Disperse Red 60 (Classic Dyestuff, Brentwood, United States), whose structures are shown in Figure 1. The ChemDraw Ultra 12.0 software was used to draw the chemical structures of the dyes.

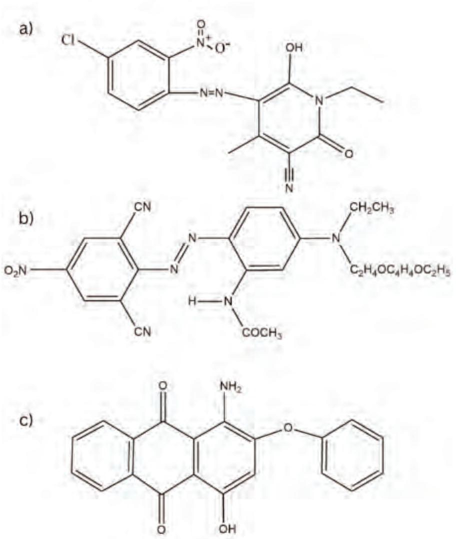

Figure 1: Chemical structures of used dyes
a) Dispese Yellow 211, b) Disperse Blue 337 and
c) Disperse Red 60

2.1.2 Chemicals

The following chemicals were used for dyeing the polyester knitted fabric: dispersing agent Univadin DP (Iskozh Co., Neftekamsk, Bashkortostan, Russia), glacial acetic acid (Zorka Pharma-Hemija DOO, Šabac, Serbia). For reductive cleaning of the cylinder, the following chemicals were used: Solopol WO detergent (SC Johnson Professional, Kuala Lumpur, Malaysia), sodium hydroxide (Zorka Pharma-Hemija DOO, Šabac, Serbia), sodium dithionite (Zorka Pharma-Hemija DOO, Šabac, Serbia), while sodium hydrogensulphite (Zorka Pharma-Hemija DOO, Šabac, Serbia) and sodium hydroxide (Zorka Pharma-Hemija DOO, Šabac, Serbia) are used for reductive cleaning of polyester knitted fabric.

2.2 Methods

2.2.1 Reduction cleaning of cylinder

To prevent the polyester fibers from being dyed unevenly, the cylinders must undergo a reduction cleaning process before dyeing. The cylinders are first filled with water heated to 70-80 °C to which are added: 3 g·dm^{-3} Solopol WO detergent, 6 g·dm^{-3} sodium hydroxide, 3 g·dm^{-3} sodium dithionite. After 30 minutes, the cylinders are thoroughly washed and dried and are ready for dyeing the polyester knitted fabric.

2.2.2 Dyeing process

Dyeing of polyester knitted fabric was carried out by the process of exhaustion at elevated temperature and under pressure (135 ^{o}C) - HT dyeing. The bath ratio was 1:20. The dye solution contained acetic acid, dispersant and disperse dye. Dyeing of polyester starts at 50 °C, 40 minutes, after that the temperature is raised to 135 °C and dyed for 60 minutes. Table 1 shows the dyeing recipes used at dye different concentrations of Disperse Red 60 - one-component procedure, mixtures of red dye Disperse Red 60 and yellow dye Disperse Yellow 211 - two-component system and mixtures of three dyes: red - Disperse Red 60, yellow - Disperse Yellow 211 and blue - Disperse Blue 377 – three-component system. Dyeing was performed on an Ahiba Texomat dyeing machine, model GVII (Allstates Textile Machinery, Williamston, South Carolina, United States).

2.2.3 Reduction cleaning of polyester after dyeing

After dyeing, the float was cooled to 55-60 °C and the polyester knitted fabric was reductively cleaned for 30 minutes at 70 °C in a solution to which 15 g•dm^{-3} of sodium hydroxide and 5 g•dm^{-3} of sodium hydrogensuffite were added. Then the polyester is washed with hot and cold water. This treatment is necessary in order to remove the remains of unfixed paint and auxiliaries from the polyester fibers.

2.2.4 Color strength of dyed polyester kniited fabric

Reflectance spectra, color strength, and CIELab coordinates of dyed polyester samples were recorded on a Color-Eye 3000 spectrophotometer (Jacksonville, Florida). 16 measurements were made every 20 nm in the range 400-700 nm. The measured values are compared with the values of the light intensity coming from the other surface of the sphere outs ide the sample. The percentage of reflection as a function of wavelength is expressed in relation to a physically ideal white body (R=100% at all wavelengths) and an ideal black body (R=0% at all wavelengths).

K/S values of dyed fabric samples were calculated using the Kubelka-Munk equation [20]:

$$K/S = (1-R)^2/2R \quad (1)$$

where *K* is the absorption coefficient, *S* is the scattering coefficient, and *R* is the decimal part of the reflection of the dyed sample.

3. RESULTS AND DISCUSSION

By applying color metrics, CIELab coordinates were obtained for undyed, dyed samples in one-component, two-component and three-component dyeing systems. Figures 2-4 show K/S values for polyester

Table 1: Recipes for dyeing polyester knitted fabric in one-component, two-component and three-component systems

One-component system					
Conc. of dye, %	Mass of dye, g	Mass of sample, g	Volume of CH_3COOH, cm^3	Volume of dispersing agent, cm^3	Volume of float, cm^3
1	0.1	10	0.10	0.40	200
4	1.6	40	0.40	1.6	800
Two-component system					
1	0.05+0.05	10	0.10	0.40	200
4	0.8+0.8	40	0.40	1.60	800
Three-component system					
1	0.08+0.06+0.06	10	0.10	0.40	200
4	0.64+0.48+0.48	40	0.40	1.60	800

knitted fabric dyed in one-component, two-component and three-component systems at different dye concentrations. In Figure 2 for polyester knitted fabric dyed with one dye at different concentrations, the maximum value of K/S for dyed polyester at 1% concentration is 13.97, while for dyed with 4% dye concentration it is 27.25. The sample dyed in a two-component system at a dye concentration of 1% (Disperse Yellow 211 - 0.50% + Disperse Red 60 - 0.50%) has a maximum K/S value of 17.31, while dyed with 4% (Disperse Yellow 211 - 2% + Disperse Red 60 - 2%) has 25.55. Sample dyed in a three-component solution has the highest K/S value at a dye concentration of 4% (Disperse Red 60 - 1.20% + Disperse Yellow 211 - 1.60% + Disperse Blue 377 - 1.20%), i.e. 29.36, while with 1% dye concentration (Disperse Red 60 - 0.30% + Disperse Yellow 211 - 0.40% + Disperse Blue 377 - 0.30%) 11.75. The sample dyed in a three-component dyeing system at a concentration of 1% has the lowest K/S value, while the sample dyed with 4% dye concentration in a three-component system has the highest K/S value.

Tables 2-5 show CIELab values for undyed, dyed in one-component, two-component and three-component dyeing systems at different dye concentrations. Dyed samples were recorded under three different light sources. The parameter L* has the highest value for the undyed sample at the light source A-10. The higher the L* value, the more brightly dyed the sample. The lowest L* value was observed for the sample dyed with 4% in the three-component system, which means that this sample is the darkest dyed. a* has the smallest and negative value for the undyed sample at the light source -0.40, which means that the sample is more green than red. The highest and most positive a* value is visible in the sample dyed with 1% dye concentration in a one-component dyeing system, i.e. 48.75 (light source D65-10). A positive a* value indicates that the sample is more red than green. For the sample dyed with 1% dye with one dye, the smallest and negative value of b* -1.29 was observed, which means that the sample is more blue than yellow. The highest and positive b* value is visible in the sample dyed with a mixture of two dyes - Disperse Yellow 211 + Disperse Red 60 at a dye concentration of 4% (b*=60.93, light source A-10). A positive value of b* means that the sample is more yellow than blue. Chroma C* has the lowest value for the undyed sample, i.e. 3.86 (light source A-10), while the highest value is for the sample dyed in a two-component dyeing system at a dye concentration of 4% (C*=74.70, light source A-10). The value of hue H* has the lowest value for the sample dyed in a three-component dyeing system with 1% dye at light source D65-10 (H*=4.41). The highest value of H* was observed for

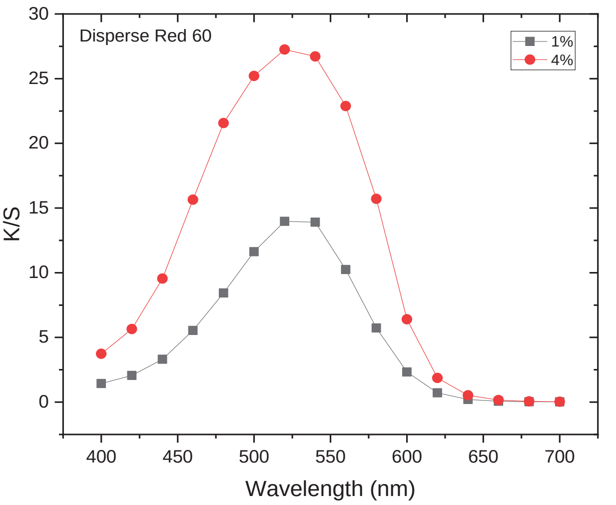

Figure 2: K/S of polyester knitted fabric in a one-component system - red dye Disperse Red 60

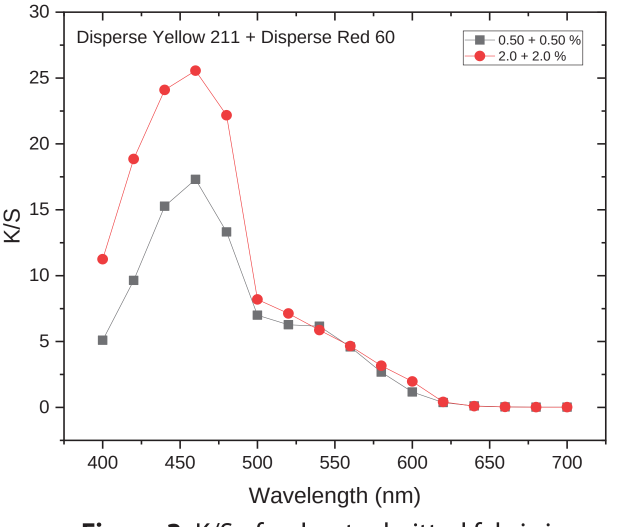

Figure 3: K/S of polyester knitted fabric in a two-component system - yellow dye Disperse Yellow 211 + red dye Disperse Red 60

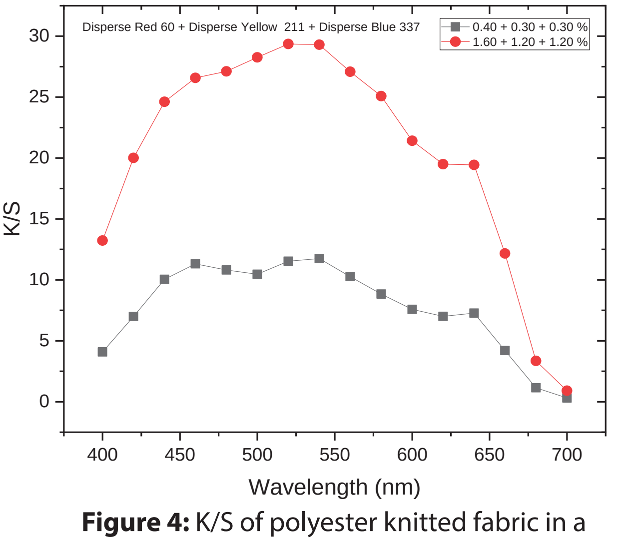

Figure 4: K/S of polyester knitted fabric in a three-component system - red dye Disperse Red 60 + blue dye Disperse Blue 337 + yellow dye Disperse Yellow 211

polyester dyed with one dye at a concentration of 1% and light source D65-10, ie. 358.49.

Table 2: CIELab paramters for undyed sample

Undyed sample					
Light source	L*	a*	b*	C*	H*
D 65-10	92.02	-0.40	3.85	3.87	95.99
A-10	92.24	0.70	3.80	3.86	79.51
TL-84-10	92.16	-0.04	4.24	4.24	90.60

Table 3: CIELab values for dyed polyester knitted fabric in a one-component system at different dye concentrations

Disperse Red 60					
Dye concentration 1%					
Light source	L*	a*	b*	C*	H*
D 65-10	36.93	48.75	-1.29	48.77	358.49
A-10	43.25	47.64	12.40	49.23	14.59
TL-84-10	38.36	41.96	-0.37	41.96	359.49
Dye concentration 4%					
D 65-10	27.26	43.88	5.43	44.22	7.05
A-10	33.53	45.04	18.41	48.66	22.23
TL-84-10	27.67	34.93	5.18	35.31	8.44

Table 4: CIELab values for dyed polyester knitted fabric in a two-component system at different dye concentrations

Disperse Red 60 + Disperse Yellow 211					
Dye concentration 0,50 + 0,50% (1%)					
Light source	L*	a*	b*	C*	H*
D 65-10	44.33	40.00	38.65	55.63	44.02
A-10	50.96	44.21	49.64	66.48	48.31
TL-84-10	46.64	37.25	43.19	57.03	49.22
Dye concentration 2.00 + 2.00 % (4%)					
D 65-10	46.34	38.69	50.70	63.78	52.65
A-10	53.05	43.21	60.93	74.70	54.65
TL-84-10	48.98	36.11	55.78	66.45	57.09

Table 5: CIELab values for dyed polyester knitted fabric in a three-component system at different dye concentrations

Disperse Yellow 211 + Disperse Red 60 +Disperse Blue 377					
Dye concentration 0.40 + 0.30 + 0.30 (1%)					
Light source	L*	a*	b*	C*	H*
D 65-10	26.07	8.50	0.66	8.52	4.41
A-10	27.23	9.55	3.31	10.10	19.13
TL-84-10	26.09	7.37	0.87	7.42	6.75
Dye concentration 1.60 + 1.20 + 1.20 % (4%)					
D 65-10	15.02	6.13	-0.35	6.14	356.74
A-10	15.85	7.20	1.50	7.35	11.76
TL-84-10	15.03	4.74	-0.28	4.75	356.57

4. CONCLUSION

Based on the obtained results, the following can be concluded:

Increasing the dye concentration in all systems (one-component, two-component and three-component) leads to an increase in the K/S value, which indicates a higher degree of saturation and more intense coloring;

The highest value of the K/S parameter (29.36) was recorded for the sample dyed in a three-component system with 4% dye concentration, which shows that the combination of several disperse dyes enables deeper and more saturated dyeing;

The lowest L* values were recorded in the darkest samples (4% three-component system), while the lightest sample was unstained, which confirms the correlation between L* and dyeing intensity;

The values of a* and b* parameters show a shift towards red and yellow tones with an increase in the dye concentration and the number of components in the dyeing, especially expressed in the two-component system (Disperse Yellow 211 + Disperse Red 60);

The highest values of chromaticity (C*) were recorded in the two-component system with 4% concentration (C*=74.70), which indicates pronounced purity and color intensity;

The hue (H*) values confirm that the dyeing system and concentration affect the shift in the color spectrum, where three-component dyeing produced darker and warmer shades compared to one-component.

It can be concluded that multi-component dyeing systems (especially three-component) and higher concentrations of dyes give more intense, darker and chromatically richer tones, which is important for achieving specific visual effects and optimizing the dyeing process of polyester materials.

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