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APPLICATION OF BIMETALLIC NANOPARTICLES IN DYEING WOOL FABRICS

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Abstract

In this study, nanoparticles of copper Cu^{2+}, iron Fe^{3+}, aluminum Al^{3+} and zinc Zn^{2+} salts, which have high activity compared to traditional microscale mordants, as well as their bimetallic combinations Cu^{2+}/Fe^{3+}, Al^{3+}/Cu^{2+}, Al^{3+}/Fe^{3+}, Cu^{2+}/Zn^{2+}, Zn^{2+}/Al^{3+}, were used in the dyeing of wool fiber. Their influence on the mechanism of formation of different colours and colour intensity during the dyeing process using the Indigofera Tinctoria L. plant was assessed. When using nanomordants of the Al^{3+}/Cu^{2+} combination, light blue and blue-violet colours are obtained, Cu^{2+}/Zn^{2+} – bright blue and blue-green colours, Zn^{2+}/Al^{3+} – light blue and sky-blue colours. Combinations involving Cu^{2+} nanoparticles contributed to the saturation of the color of wool fabrics, Al^{3+} nanoparticles played an important role in fixing the color and preserving the fiber structure, and Cu^{2+} nanoparticles served to saturate the color. Although an increase in colour brightness was observed in the presence of Fe^{2+} nanoparticles, it was found that environmental restrictions must be observed when using them.

Key words
natural dye, bimetallic mordant, color tone, color fastness, washability.

Introduction

In recent years, environmental protection, reducing negative impacts on human health and implementing sustainable production principles have become increasingly important in the global textile industry.

In particular, toxic wastewater generated by the use of synthetic dyes, allergic effects and environmental concerns have further increased interest in natural dyes. In this regard, many scientific studies are being conducted on the use of natural dyes, including dyes obtained from the *Indigofera Tinctoria L.* plant. [1-2].

It is noted that the insolubility of indigo dye in water and the need to convert it into a reduced (leuco-indigo) form before the dyeing process create certain technological difficulties [3]. Particular attention should be paid to dyeing protein fibers, especially wool, with indigoid dyes in an alkaline environment, since wool is very sensitive to alkali [4]. In works devoted to the study of the chemical nature of wool fiber, it was shown that the presence of the protein keratin [5], amine, carboxyl and hydroxyl functional groups that form its basis, is of decisive importance in the dyeing process [6]. It has been proven that the structure of wool fiber macromolecules influences the diffusion and fixation of dye molecules, so the use of mordants is an important factor in increasing color fastness [7-11].

Materials and methods of research

The experiments were carried out on a semi-wool fabric with a thickness of 1.37 mm, a fabric made of a mixture of wool and cotton (63:37).

In the course of the study, the indigo plant, Indigofera Tinctoria L., was used as a natural dye, as well as nanobimetallic etchants Cu^{2+}/Fe^{3+}, Al^{3+}/Cu^{2+}, Al^{3+}/Fe^{3+}, Cu^{2+}/Zn^{2+}, Zn^{2+}/Al^{3+} with a particle size of ≈ 23 nm and a purity of >99%. The concentration of nanosalts during the dyeing process was lower than with the traditional method and was approximately Cu^{2+} – 0.5 g/l, Fe^{3+} – 0.4 g/l, Al^{3+} – 1.0 g/l and Zn^{2+} – 0.6 g/l. The mordanting process was carried out in a

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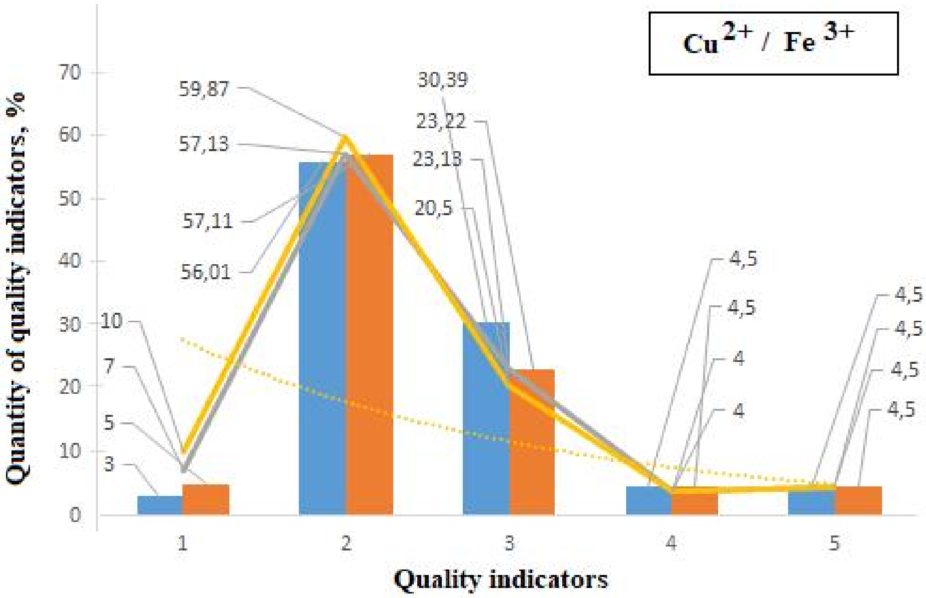
slightly acidic environment with a pH of 4.5–5.5 at a temperature of 60°C for 45 minutes. After this step, the fabric was transferred directly to the dyeing process.

Before use, the dye from Indigofera Tinctoria L. was converted into a water-soluble reduced form, leucoindigo. The reduction process of Indigofera Tinctoria L. (5 g/l) was carried out in the presence of 1-2 g/l sodium carbonate (alkaline medium, pH=9) and a reducing agent at a temperature of 55°C for 30 minutes. The light yellow-green color of the solution resulting from the reduction indicates that the process is proceeding correctly. The wool fabric was then placed in a solution of Indigofera Tinctoria L. dye and dyed at 50°C for 20 minutes. At the final stage, the dyed woolen fabric was washed with neutral soap with a concentration of 2 g/l at a temperature of 40°C for 15 minutes and then dried.

The results obtained and their discussion

In a study investigating the effect of the type of bimetallic nanomordant on the dyeing quality of wool fabric, five samples of semi-wool fabric were dyed under the same conditions and with the same concentrations of bimetallic nanomordants, as well as in four different concentrations of dyeing solution. When using a bimetallic combination, each ion was obtained in the minimum effective amount.



A

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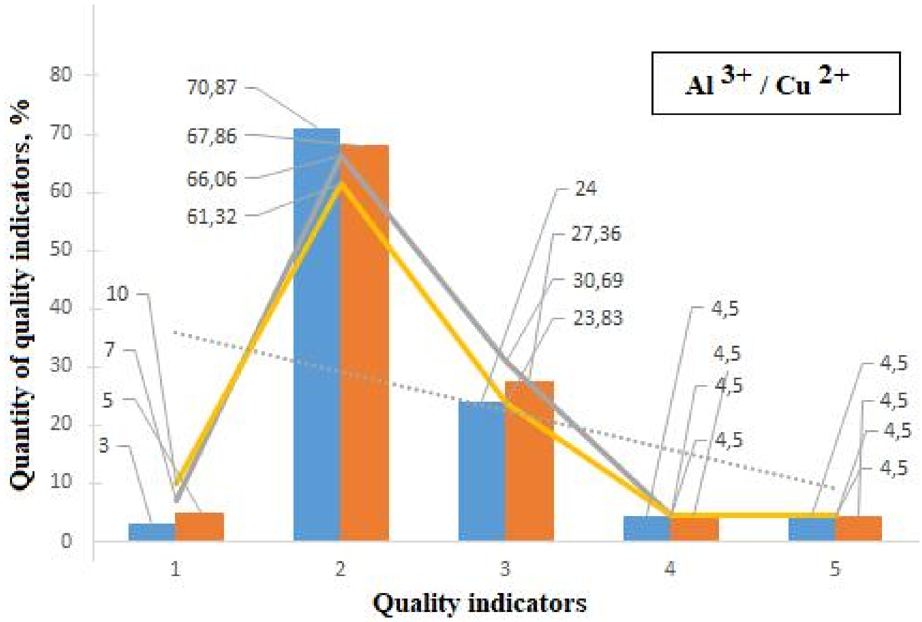

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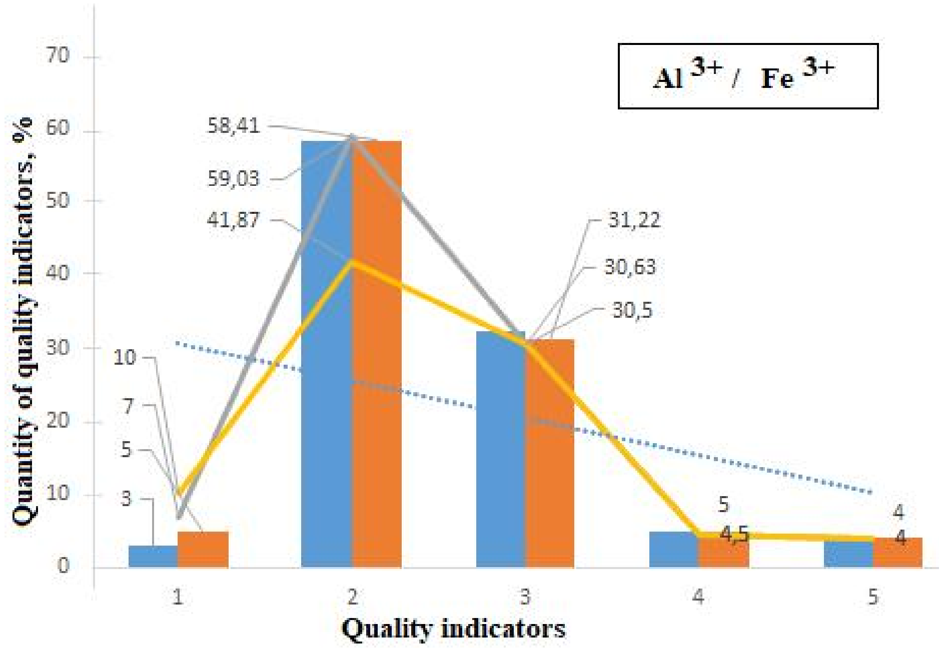

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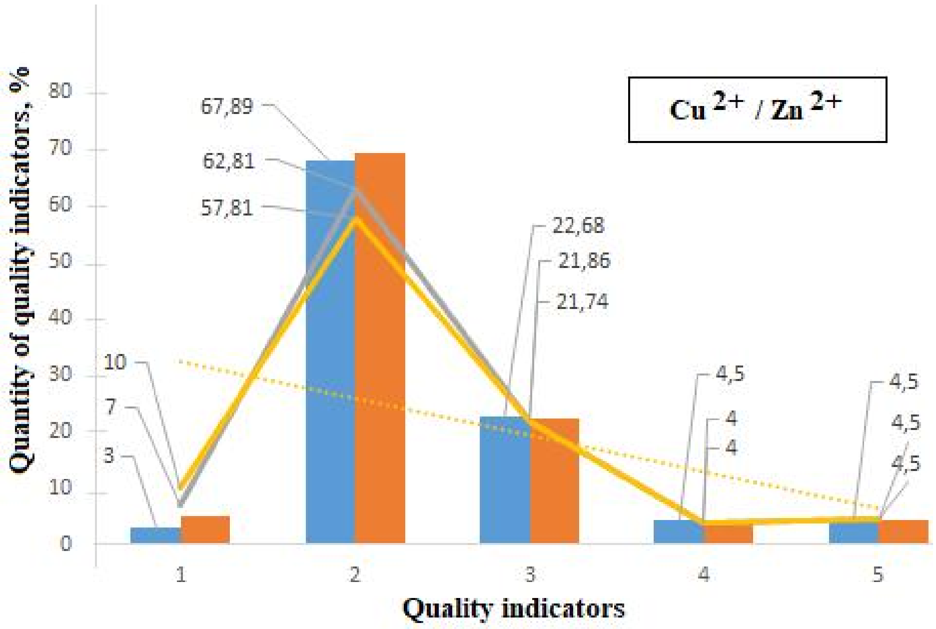

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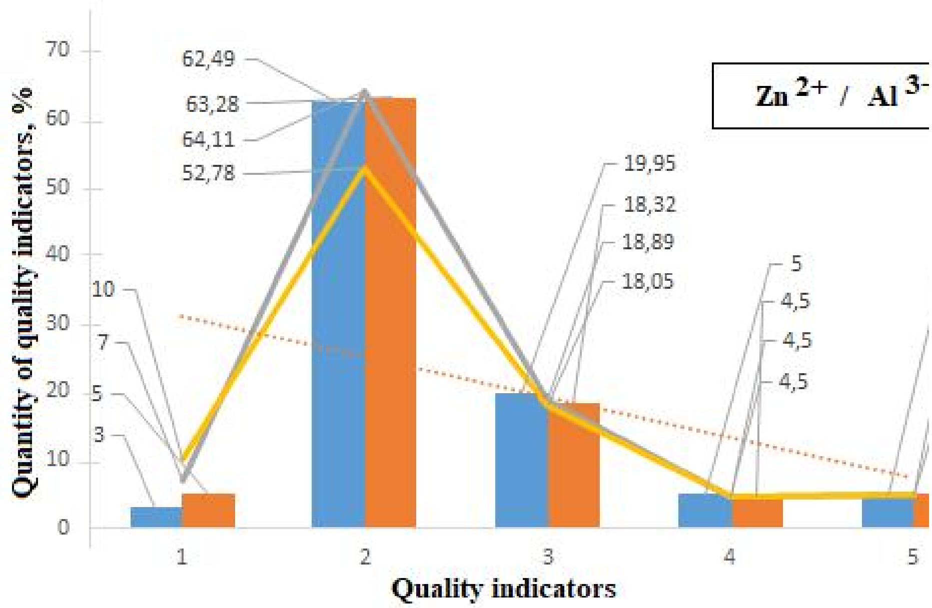

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Figure 1. Dependence of color characteristics of woolen fabrics on the concentration of dye and the type of bimetallic nanomordant;
A – Cu^{2+}/Fe^{3+} ; B – Al^{3+}/Cu^{2+} C – Al^{3+}/Fe^{3+},
D – Cu^{2+}/Zn^{2+}, E – Zn^{2+}/Al^{3+}

* *Note: 1. Dye concentration, %; 2. Color brightness, L*; 3. Color saturation, C*; 4. Color fastness to soap; 5. Color fastness to sweat.*

Staining with a dye solution from Indigofera Tinctoria L. was carried out using various compositions of bimetallic nanoetchants. The color characteristics of dyed wool fabric were determined using a laboratory colorimeter under standard D_{65} irradiation.

The results (Fig. 1) showed that combinations of Al^{3+}/Cu^{2+} and Cu^{2+}/Zn^{2+} in the form of various bimetallic nanomordants provide color saturation and uniform color distribution on wool fabrics. In combinations involving Fe3+, it was observed that the color darkened and became gray. In addition, the color characteristics of the colored samples obtained by Cu^{2+}/Fe^{3+} nanoetching formed an exponential function graph. Linear function graphs appeared with the

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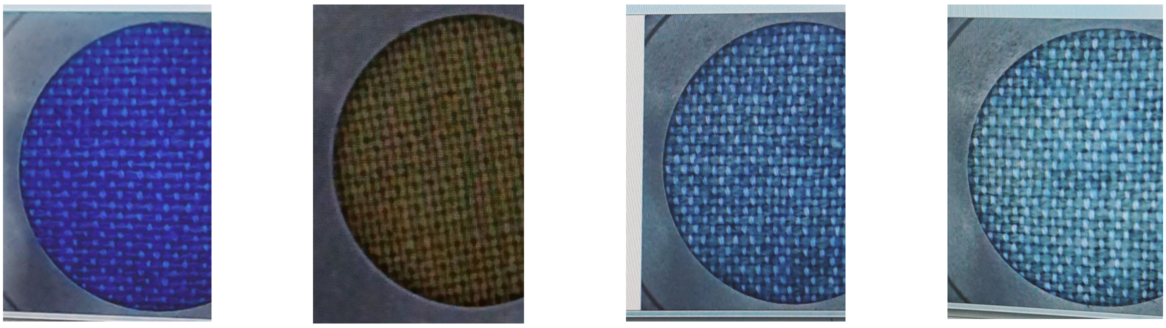
participation of Al^{3+}/Cu^{2+}, Al^{3+}/Fe^{3+}, Cu^{2+}/Zn^{2+}, Zn^{2+}/Al^{3+} nanocrystals. This represents a uniform process in which the change in the function is proportional to the change in the argument. The decline in the exponential function graphs reflects the decrease in color brightness in the dyed samples. We see that during the dyeing process, increasing the dye concentration from 3% to 7% shifts the L b* coordinate from blue to yellow, and the a* coordinate from green to red. Thus, it was found that at all dye concentrations, bright light colours are formed in the presence of these nano-etchants.

When using nanomordants of the Al^{3+}/Cu^{2+} combination, light blue and electric colours are obtained, Cu^{2+}/Zn^{2+} – blue-green colours, Zn^{2+}/Al^{3+} – light blue and sky-blue (Fig. 2).



Al^{3+}/Cu^{2+} Cu^{2+}/Zn^{2+} Zn^{2+}/Al^{3+} Al^{3+}/Cu^{2+}

Wool fabric dyed with Indigofera Tinctoria L.

Figure 2. Dependence of the color of dyed woolen fabric

The possibility of producing turquoise shades using bimetallic Al^{3+}/Cu^{2+} salts as nano mordants in the dyeing process is shown in the dyed samples in Figure 2. In this case, low dye concentration in the solution resulted in dull colors, while increasing the dye concentration resulted in increased color intensity and saturation. Cu^{2+} ions darkened the indigo color, while Al^{3+} ions increased its saturation.

The color intensity of the samples increases proportionally to the increase in the dye concentration, however, the color fastness of all samples when washed is 4-4.5. Typically, when dyeing fibers with natural dyes, covalent bonds are formed with the fiber, which allows for the production of colors that are resistant to various types of processing. In studies, low color fastness values may be related to the pH of the solution. Since cotton fiber, one of the components of the fabric, has a cellulose base, its covalent bond with the active dye occurs in an alkaline environment (pH 10.0–10.5). Under these conditions, the hydroxyl groups of cellulose are ionized, which increases their reactivity, and the hydrogen chloride released as a result of the reaction is neutralized. As a result, the bond between the fiber and the dye is protected from hydrolysis.

Conclusions

According to the obtained experimental data, when dyeing with all types of salt mordants, with the exception of the bimetallic combination Al^{3+}/Fe^{3+}, a decrease in color saturation is observed as the concentration of the dye in the solution increases. Despite the fact that the dye concentration in the solution changed in similar ranges during treatment with all bimetallic nanomordants, the shades on the wool fabric samples differed. Despite the fact that the dye concentration in the solution changed in similar ranges during treatment with all bimetallic nanomordants, the shades on the wool fabric samples varied. The results obtained were assessed based on spectrophotometric analysis of colour intensity, as well as indicators of resistance to wet processing. Woolen fabrics dyed using nanobimetallic mordants were characterized by

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greater color complexity and resistance to physical and chemical influences compared to samples obtained by traditional methods.

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