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OPTIMIZATION OF ACRYLIC FIBER DYEING IN LABORATORY CONDITIONS

Goran Amin[1], Sandra Konstantinovic[1], Igor Jordanov[2], Dragan Djordjevic[1]

[1] University of Nis, Faculty of Technology, Leskovac, Serbia

[2] Faculty of Technology and Metallurgy, Skopje, North Macedonia

ABSTRACT

Optimization of the factory recipe for dyeing acrylic fibers in laboratory conditions was done in this article. The basic color The dye Basic Red 46 was used for dyeing, while uncolored acrylic fabric in plain weave was used as the substrate. The optimized recipe for dyeing acrylic fibers with a basic dye is partly different from the recommended factory recipe. More efficient dyeing through optimization means more dye on the fiber and less waste dye remaining in the bath after dyeing, which certainly facilitates the purification of liquid waste. Dyeing in laboratory conditions has its specificities, but it is a good basis for the formation of dyeing parameters in industrial conditions. Relatively smaller differences for numerous values of the parameter K/S, for individual parameters in the recipe, may lead to thinking about a compromise for the selection of operating parameters. Optimized and factory recipes are not universal and are not always valid, on the contrary, the changing chemical nature of acrylic fibers and dyes will affect the choice of working dyeing parameters, which constantly requires new analysis and laboratory testing, as a prerequisite for industrial dyeing.

Key-words**:** acrylic fiber, dyeing, Basic Red 46, optimization.

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ОПТИМИЗИРАНЕ НА БОЯДИСВАНЕТО НА АКРИЛНИ ВЛАКНА В ЛАБОРАТОРНИ УСЛОВИЯ

Горан Амин[1], Сандра Константинович[1], Игор Йорданов[2], Драган Джорджевич[1]

[1]Университет в Ниш, Факултет по технологии, Лесковац, Сърбия

[2]Факултет по технология и металургия, Скопие, Северна Македония

РЕЗЮМЕ

В тази статия е оптимизирана фабричната рецепта за боядисване на акрилни влакна в лабораторни условия. Багрилото Basic Red 46 е използвано за боядисване на неоцветена акрилна тъкан в гладко тъкане и е използвано като субстрат за боядисване. Оптимизираната рецепта за боядисване на акрилни влакна с основно багрило е частично различна от препоръчителната фабрична рецепта. По-доброто оптимизиране на боядисването означава повече багрило върху и във влакното и по-малко отпадъчно багрило, останало във ваната след боядисване, което улеснява пречистването на течните отпадъци. Багренето в лабораторни условия има своите специфики, но е добра основа за формиране на параметрите на багрене в индустриални условия. Относително по-малките разлики за множество стойности на параметъра K/S, за отделните параметри в рецептата, могат да доведат до мислене за компромис при избора на работни параметри. Оптимизираните и фабрични рецепти не са универсални и не винаги са валидни, напротив, променящата се химическа природа на акрилните влакна и багрила ще повлияе на избора на работни параметри на боядисване, което постоянно изисква нови анализи и лабораторни изследвания.

Ключови думи: акрилно влакно, багрене, Basic Red 46, оптимизация.

INTRODUCTION

Acrylic fibers, once composed of polyacrylonitrile homopolymers, exhibited great defects during dyeing, which is why great efforts were made by manufacturers to come up with new, modified types of these fibers. The disadvantages were eliminated by copolymerizing acrylonitrile with other vinyl monomers that serve as plasticizers. The dyeing of polymers and fibers is improved, the reactivity, hydrophilicity, and elasticity of acrylic fibers are increased 1.

Today, those fibers that contain at least 85% acrylonitrile are called "acrylic fibers". Among acrylic fibers, the most common are those with acidic (anionic) terminal groups that have a strong affinity for basic dyes. The anionic nature of nitrile groups gives acrylic fibers an affinity for basic dyes, where a cationic auxiliary agent is used as a retarder to compensate for the negative charge of the fibers 2.

The process of dyeing acrylic fibers brings a qualitatively new product but also leaves behind liquid waste that needs to be disposed of. Optimization of dyeing, in this case, can bring better quality dyed textiles, fewer waste dyes, energy savings, lower costs, etc.

When dyeing acrylic fibers (commercial dyes) in various color tones, the correct selection of basic dyes is important. It has been shown that basic dyes can mutually influence the speed of transition to the fiber. To achieve uniform coloring and economic dyeing, the selected dyes in combination must have the same speed of transition to the fiber 3.

It should be noted that acrylic fibers are dyed with basic dyes only above the glass transition temperature Tg, which has a characteristic value for each type of fiber and most fibers are between 70 and 80 C. Basic dyes form a heteropolar bond with the anionic groups of the fibers. The number of anionic sites in the fiber determines the saturation value, S_f, that is, the maximum amount of color that the fiber can take 4.

Dyeing with basic dyes takes place by the mechanism of ion exchange or by a simple distribution of ions through the three steps involved in dyeing 5.

(a) Adsorption of dye cations on the fiber surface.

(b) Diffusion into the fiber.

(c) Occupancy within the fiber.

The ionic attraction between the basic dye and the sulfonic group in the acrylic fibers is strong, which gives a high color fastness to washing. The solid and dense physico-chemical nature of acrylic fibers and the strong bond between the dye and the fibers can result in poor migration and leveling properties during dyeing, but that is why they have a very high color fastness to light 6, 7.

In this work, the factory recipe for dyeing acrylic fibers with a basic dye in laboratory conditions was optimized. It was determined that some of the key parameters should be changed to optimize the classic dyeing, with savings and better exhaustion of the dye from the dyeing bath.

EXPERIMENTAL PART

Material used

The basic dye, C.I. Basic Red 46 (DyStar Colours Distribution GmbH, Germany), molecular formula $C_{18}H_{21}BrN_6$, and molar mass 401.3 g/mol, was used for dyeing. The dyestuff is in the form of a dark red powder, it dissolves in water, mainly used for dyeing textiles made of acrylic fibers, and it can also be used in textile printing.

As a substrate for dyeing, an acrylic fabric in plain weave was used, the warp setting is 17 cm^{-1}, the weft setting is 15 cm^{-1}, and the warp and weft count is 62 tex. Before dyeing, the fabric was washed (2 g/dm^3 nonionic detergent, Lavan NKF- Textilcolor AG, Switzerland, 1:30, 60 °C, 30 min), thoroughly rinsed and air-dried.

Work procedure

It started from the basic recipe recommended by the manufacturer: basic dye 2%, bath scale 1:30, Alviron W (Textilcolor AG, Switzerland) 0.5 g/dm^3, Na_2SO_4 (Centrohem, Serbia) 5%, TC Retard PAN (Textilcolor AG, Switzerland) 1%, 98 C, 45 min, pH 4 (HCOOH, Centrohem, Serbia). Constant parameters were: dye concentration, bath scale, and amount of leveling agent, while other parameters were varied for optimization and selection of the most favorable results. Variation of the pH value for an alkaline medium was carried out with the help of Na_2CO_3 (Centrohem, Serbia).

The color of the fabric was measured using a reflectance spectrophotometer (HunterLab ColorQuest XE diffuse/80), which is connected to a personal computer. The Gurevich-Kubelka-Munk function, color strength (K/S), was determined on the apparatus with the help of appropriate software.

RESULTS AND DISCUSSION

The dyeing process or the reaction between the dye and the acrylic takes place through the sorption process, which includes a pH-dependent dyeing mechanism. With basic dyes, electrostatic forces between dye molecules and acrylic fibers come to the fore. Sorption and fixation of dyer are separate quantities and each of them can be determined and presented depending on the influencing factors 7.

Dyeing optimization means choosing the best combination of factors important for successful dyeing that leaves the least amount of waste dyer at the end of the dyeing process.

The influence of the pH of the bath on dyeing

The pH of the solution has a significant effect on effective and high-quality dyeing with a basic dye. Figure 1 shows the dyeing results, which directly define the best pH value of the solution when a higher color strength, K/S, is obtained, i.e. the highest color strength of the acrylic fabric. The K/S parameter represents the amount of dye on the textile and is directly proportional to the amount of dye bound to the textile material. The highest values for the parameter K/S are achieved at pH = 5, which means that under these (acidic) conditions, most dye is bound to the acrylic fiber in the fabric.

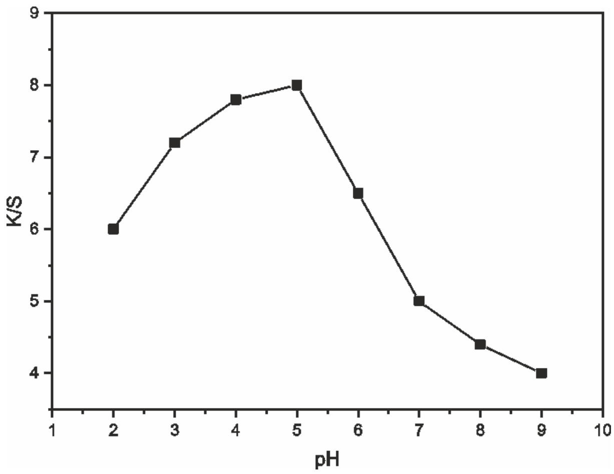

Figure 1. Effect of pH solution on the dyeing of acrylic fabric with basic red dye (basic dye 2 %, Alviron W 0.5 g/dm^3, Na_2SO_4 5 %, TC Retard PAN 1 %, 1:30, 98 C, 45 min)

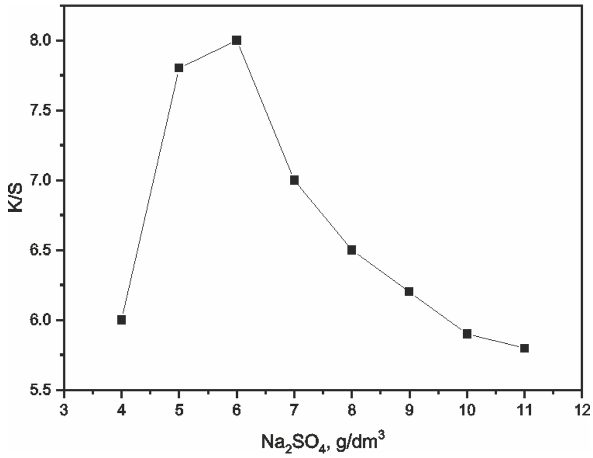

Figure 2. Effect of salt-electrolyte on the dyeing of acrylic fabric with basic red dye (basic dye 2 %, Alviron W 0.5 g/dm^3, pH 4, TC Retard PAN 1 %, 1:30, 98 C, 45 min)

Effect of electrolytes

The bath exhaustion during the dyeing process depends on the concentration of the electrolyte. As a rule, dye exhaustion increases with the increase in electrolyte concentration. The presence of an electrolyte is necessary especially in the case of using dyes with high affinity because it slows down the migration of the dye, which achieves a better uniformity of coloring 8.

Figure 2 shows the results related to the influence of the concentration of salt-electrolyte (sodium sulfate) on the color strength for dyed textile samples with a basic dye. It can be seen from the figure that with the increase in salt concentration, the color strength continuously increases. After reaching the maximum, the growth slows down and decreases with higher amounts of electrolytes. At the amount of salt of 6%, the strongest coloring is achieved on the acrylic fabric, i.e. K/S = 8.

Effect of dye retarder

Dye retarders are used to reduce the speed of dyeing, i.e. to achieve more uniform and equal coloring of textile materials during the dyeing process. The high affinity of the dye for the selected textile sample can make the dyeing happen very quickly, in just a few minutes, however, with a side effect, uneven or colorful dyeing on the textile 9.

From Figure 3, it can be seen that the amount of 0.8% retarder TC Retard PAN is quite sufficient to exhaust enough dye on the textile material without causing problems in color uniformity.

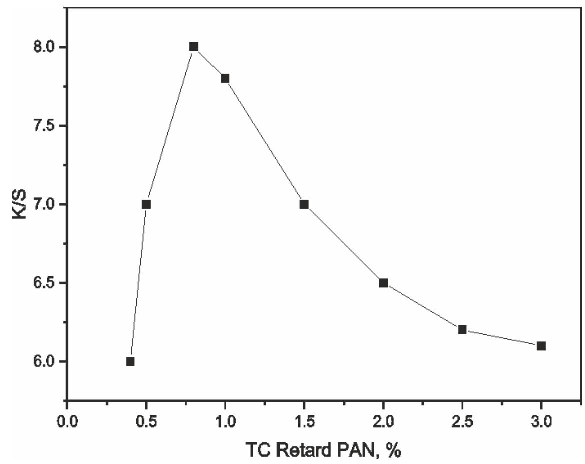

Figure 3. Effect of dye retarder on the dyeing of acrylic fabric with basic red dye (basic dye 2 %, Alviron W 0.5 g/dm^3, pH 4, Na_2SO_4 5 %, 1:30, 98 C, 45 min)

Effect of temperature

The rate of dyeing depends significantly on the temperature and in all cases increases with its increase. The increase in dye sorption with temperature can be attributed to an increase in the number of active surface sites available for sorption on the fiber, and an increase in porosity, swelling, and total free volume inside the fiber 2, 10.

The influence of temperature on the ability to dye acrylic fabric with a basic dye was tested at different temperatures (60 - 100 C). Figure 4 shows that the color strength increases continuously with the dyeing temperature up to 100 C. The worse effect at lower temperatures can be attributed to the insufficient degree of swelling of the fibers, and in connection with this, the lower migration and aggregation of the dye into the interior of the fibers.

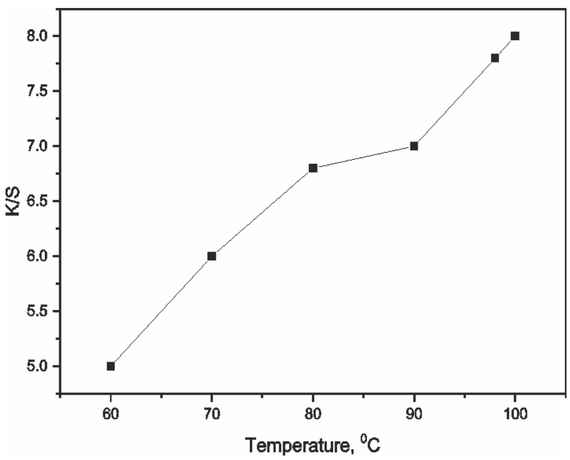

Figure 4. Effect of temperature on the dyeing of acrylic fabric with basic red dye (basic dye 2 %, Alviron W 0.5 g/dm^3, pH 4, Na_2SO_4 5 %, TC Retard PAN 1 %, 1:30, 45 min)

The influence of the dyeing time

The processing time, as a valuable and important processing factor, has its influence on the efficiency of the processing, primarily on the greater exhaustion of the dye from the dyeing bath. In principle, treatments that last a longer time sometimes bring better results, although not always to the extent that would be sufficient for these parameters to be accepted as working. From the point of view of economy and rationality, determining the length of processing is of crucial importance 3, 9.

The influence of the processing time on the color strength of the acrylic fabric was tested from 25 to 60 min. From Figure 5, you can see the continuous growth of the parameter K/S, i.e. color strength, with a slight slowdown after 45 min. Processing for 60 minutes is enough to reach the maximum amount of color on the fiber in the fabric. Of course, the question always arises, is it worth it, and to what level should the dyeing be prolonged for the sake of a slight increase in the color strength, while wasting energy and time?

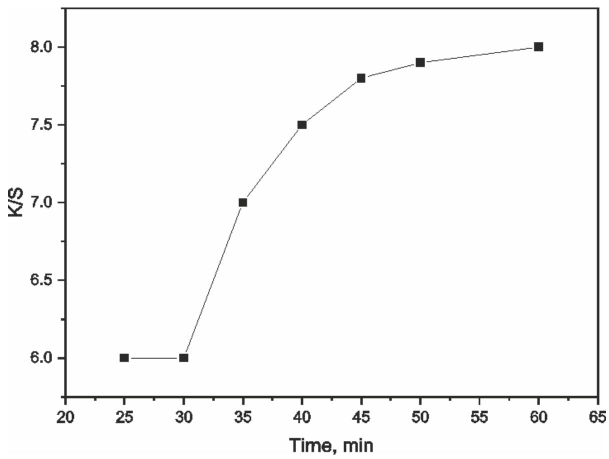

Figure 5. Effect of time on the dyeing of acrylic fabric with basic red dye (basic dye 2 %, Alviron W 0.5 g/dm^3, pH 4, Na_2SO_4 5 %, TC Retard PAN 1 %, 1:30, 98 C)

Optimized recipes and dyeing conditions

Considering the performed checks of the parameters that directly affect the dyeing effects and the quality of waste-dyed water, "optimized" recipes were determined based on the previously presented results.

For the basic red dye used-optimized dyeing recipe in laboratory dyeing conditions, it looks like this:

- 1:30, bath scale (constant parameter).
- 2% dye (constant parameter).
- 0.5 g/dm^3 Alviron W, nonionic leveling agent (constant parameter).
- 6% Glauber's salt (manufacturer's recommendation 5%).
- pH 5 (manufacturer's recommendation 4).
- 0.8% TC Retard PAN, dye retarder (manufacturer's recommendation 1%).
- 100 C, dyeing temperature (manufacturer's recommendation 98 C).
- 60 minutes of dyeing (manufacturer's recommendation 45 min).

CONCLUSION

The optimized recipe for dyeing acrylic fibers with a basic dye is partly different from the recommended factory recipe. Dyeing in laboratory conditions has its specificities, but it is a good basis for the formation of dyeing parameters in industrial conditions.

In general, relatively smaller differences for numerous values of the parameter K/S, for individual parameters in the recipe, may lead to thinking about a different choice of working parameters. Namely, if in 60 min of dyeing K/S = 8, and 45 min K/S = 7.8, then it is better to save 15 min of work and energy on dyeing considering that the difference is minimal (K/S = 0,2), invisible to the naked eye.

In the end, better optimization of dyeing means more dye on and in the fiber and less waste dye remaining in the bath after dyeing, which again means easier and more successful purification of liquid waste.

REFERENCES

1. M. Novaković, Teorija i tehnologija oplemenjivanja tekstila bojenjem i štampanjem, Univerzitet u Nišu, BMG, Beograd, 1996

2. D. Stoye, W. Funke, L. Hoppe, et al, Paints and coatings, Handbook of Ullmann's Encyclopedia of Industrial Chemistry, Wiley VCH, 2006

3. M. Naeimi, M.G. Afjeh, A.A. Gharehaghaji, et al, Dyeing Behavior of Polyacrylonitrile Nanofibers: Physicochemical Parameters of Dyeing with Basic Dye in Comparison with Regular Polyacrylonitrile Fibers, Fibers and Polym., 18(9), 1724, 2017

4. A. Hou, H. Chen, Y. Xu, et al, Rapid and environmental-friendly continuous gel-dyeing of polyacrylonitrile fiber with cationic dyes, J. Cleaner Prod., 274, 122935, 2020

5. H. Xiao, C. Li, P. Wang, et al, A feasible approach for enhancing union dyeing of wool/acrylic blend fabrics with heterobifunctional cationic reactive dyes, Text. Res. J., 89(23–24), 5085, 2019

6. Z. Tian, J. Ma, Q. Liu, H. Zhang, Preparation and application of novel amphoteric acrylic retanning agents to improve dye absorption, RSC, 8, 645, 2023

7. L.K. El-Gabry, A. El-Kheir, M. Salama, et al, Acrylic/keratin composite of enhanced dyeability towards cationic and anionic dyes", Color. Technol., 132(1), 83, 2016

8. N. Vuthiganond, P. Chitichotpanya, M. Nakpathom, et al, Ecological dyeing of acrylic yarn with colorant derived from natural lac dye, J. Met. Mater. Miner., 32(4), 71, 2022

9. K. Hunger, Industrial Dyes - Chemistry, Properties, Applications, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, 2003

10. C. Qin, R-C. Tang, B. Chen, et al, Study on the Dyeing Properties of Hemicyanine Dyes. I. Acrylic Fabrics, Fibers and Polym., 11(2), 193, 2010