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DEVELOPMENT OF DYEING TECHNOLOGY AND CREATION OF A BASIC TECHNOLOGICAL SCHEME FOR THE PROCESS OF REUSING CONCENTRATED WASTEWATER (ON THE EXAMPLE, REDUCING THE CONSUMPTION OF DIRECT YELLOW LIGHTFAST DYE K)

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Abstract

The development of wastewater reuse technology in fabric dyeing is a topical issue. This will minimise the use of water and expensive dyes, reduce the cost of finished products and the environmental impact. Concentrated wastewater from batch dyeing equipment contains up to 50% of textile dyes, so it can be reused as a secondary material resource in fabric dyeing technology. Presents the results of studies of the efficiency of dyeing cotton fabrics with Direct Yellow Lightfast K dye with the reuse of concentrated wastewater: dye intensity 95–96 % compared to the standard (100 %), colour difference between the reference and test samples DE < 2, the lightness and shade indicators samples have a difference of ± 2, qualitative indicators of colour fastness are 3–4 points according to the «Grey Standard Scale. This results prove the effectiveness of dyeing cotton fabrics with Direct Yellow Lightfast K dye with the reuse of concentrated wastewater. A schematic diagram of cotton fabric dyeing technology was created. A technology for dyeing fabrics with the reuse of concentrated wastewater in the process of dyeing fabrics with direct dyes has been developed, with an average of 11 % savings in direct dye consumption per 1200 m of fabric. The dyeing according to this scheme has been tested at Private Joint Stock Company Cherkasy Silk Plant (Cherkasy, Ukraine). The spectrophotometric method was used in the course of the work; the durability of the staining was determined in accordance with the current state standards of Ukraine and international ISO standards; the Python programming language, Mathplotlib and Seaborn visualisation libraries were used to visualise the experimental data.
Keywords: dyeing and finishing production, concentrated wastewater, reuse, resource-saving technology, direct dyes, coarse calico, viscose, schematic diagram.

РОЗРОБКА ТЕХНОЛОГІЇ ФАРБУВАННЯ ТА СТВОРЕННЯ ПРИНЦИПОВОЇ ТЕХНОЛОГІЧНОЇ СХЕМИ ПРОЦЕСУ ПОВТОРНОГО ВИКОРИСТАННЯ КОНЦЕНТРОВАНИХ СТІЧНИХ ВОД (НА ПРИКЛАДІ ЗМЕНШЕННЯ ВИТРАТ БАРВНИКА ПРЯМОГО ЖОВТОГО СВІТЛОСТІЙКОГО К)

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Анотація

Створення технології повторного використання стічних вод в технології фарбування тканин є актуальним. Це приведе до мінімізації використання води та дороговартісних барвників, зменшить собівартість готової продукції та екологічне навантаження на довкілля. Концентрована стічна вода, одержана з обладнання періодичної дії фарбувального виробництва, містить у своєму складі до 50 % текстильних барвників, тому може бути повторно використана як вторинний матеріальний ресурс в технології фарбування тканини. Представлені результати досліджень ефективності фарбування бавовняних тканин барвником Прямим жовтим світлостійким К із повторним використанням концентрованої стічної води: інтенсивність забарвлення 95–96 % по відношенню до еталону (100 %), кольорова відмінність між еталонними та досліджуваними зразками DE < 2, показники світлості та відтінків мають різницю в межах ± 2, якісні показники стійкості забарвлення 3–4 бали за «Шкалою сірих еталонів». Створено принципову схему технології фарбування бавовняних тканин. Розроблено технологію фарбування тканин із повторним (циклічним) використанням концентрованих стічних вод в процесах фарбування тканин прямими барвниками з економією витрат прямого барвника в середньому 11 % на кожні 1200 п.м. тканини. Фарбування за такою схемою апробовано на ПрАТ «Черкаський шовковий комбінат» (м. Черкаси, Україна). Під час виконання роботи використовувався спектрофотометричний метод; стійкість фарбування визначалося до діючих державних стандартів України та міжнародних стандартів ISO; для візуалізації експериментальних даних використовувалися мова програмування Python, бібліотеки візуалізації Mathplotlib і Seaborn.
Ключові слова: фарбувально-опоряджувальне виробництво; концентрована стічна вода; повторне використання; ресурсозберігальна технологія; прямі барвники; бязь; віскоза; принципова технологічна схема.

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Journal of Chemistry and Technologies, 2024, *32*(4), 1119-1128

Introduction

The textile industry is known for its large consumption of water resources, dyes, and auxiliary substances. Water is utilized in nearly all processes of textile dyeing and finishing production. About 200 liters of water are needed to produce 1kg of textile, mainly for applying color or pattern to the fabric and washing the finished textile material [1]. The water usage depends on the textile material, the process of coloring fabric (dyeing or stuffing), and the technological production stage. It was established that 38 % of water is used during fabric bleaching, 16 % during dyeing, 8 % during fabric stuffing (dyeing), 14 % in boiler rooms, and 24 % for other production needs [2]. Nearly 60 billion kg of fabrics are produced annually, using up to 9 trillion gallons of water [3]. A total of $1.6 \cdot 10^6$ liters of water is required to process fabrics weighing 8,000 kg, the second largest volume of water consumed by all industries [4].

The textile industry generates various types of waste, including wastewater, gaseous emissions into the atmosphere, solid waste, and noise pollution. The textile industry wastewater, in particular from the dyeing industry, is considered one of the most polluted. It significantly impacts water and soil ecology [5; 6]. Therefore, the issue of creating resource-saving technologies for stuffing and dyeing fabrics is essential and urgent. This will lead to water and expensive dye savings, significantly reducing the cost of finished products and alleviating environmental burdens.

It is known that most of the existing dyeing and finishing industries work with outdated and imperfect technologies. Thus, their wastewaters are complex polydisperse systems of ions, dye molecules, and auxiliary organic substances. After completion of the production cycle of dyeing textile material using a certain type of textile dye, as well as inefficient fabric dyeing, 20 to 50 % of dyes enter the wastewater, which leads to significant damage to the ecological system of the region where such production facilities are located [7; 8]. It is a matter of common knowledge that during cellulose fiber dyeing (cotton fiber is used for about 50 % of the total volume of fiber consumption in the textile industry worldwide), there are 10–50 % losses of reactive dyes in wastewater, direct dyes – 5–30 %, sulfur dyes – 10–40 %. Research into dyeing technological processes leads to the increasing the productivity of dyeing by minimizing waste, optimizing procedures, saving dye losses, and automatic control of dyeing and filling processes [9], as well as arranging production processes in such a way that they cause minimal damage to the environment [10]. Therefore, it's urgent to create resource-saving technologies for circulating water supply and processing/using wastewater, which can be utilized as a secondary material resource.

World practice already has the results of such studies. Specialists discuss in the article [11] the creation of a technology for recovering and reusing spent solutions of dye baths in the textile industry. This technology has been demonstrated in the southeastern United States under production conditions at a large carpet factory when dyeing synthetic carpets. The implemented technology made it possible to solve several problems: changing the color agents' recipe of one group for many shades; reusing of dye baths within the framework of the regular production schedule; production of high-quality products using recycled dye baths; adapting the technology of dye baths reuse to the standard coloring technology at the factory. Implementing this technology has led to a notable decrease in pollutant emissions and water consumption, ranging from 25 % to 50 %. Dye bath reuse is estimated to save $180,000 annually (under the stipulation that half of the plant's baths were converted to reuse).

Article [12] presents research results on technology for processing or reusing wastewater from the textile industry (further reducing their amount into the environment). It involves modifying the process of regenerating the color pan by adding an appropriate amount of cosmetic coloring agents and auxiliary chemicals (instead of the usual procedure of discharging the spent dye bath). The reclaimed tank can be reused to dye a second batch of textiles, significantly saving additional chemicals, energy, and water.

Researchers from Brazil [13] experimentally determined the number of residual dye baths reused from reactive dyeing of cotton, pre-enzymatically treated with horseradish peroxidase. As a result of this refinement, 99 % of the wastewater's color was removed. Moreover, this process allowed further reuse and saved about 200–600 liters of water per dyeing batch of cotton fabric (200 kg).

Researchers from India [14] suggested using triethanolamine instead of sodium carbonate in the dyeing bath recipe with low (30 °C), medium (60 °C), and high (90 °C) coloring temperatures to minimize heat and energy costs for the cotton fabric coloring with direct dyes. The colored cotton fabric samples were compared to those

Journal of Chemistry and Technologies, 2024, *32*(4), 1119-1128

dyed using conventional technology. According to the results, the color strength (K/S) and color difference were acceptable regarding the traditional dyeing process with sodium carbonate at high temperatures. The cost of low-temperature dyeing has been reduced to a minimum of Rs 2.24 compared to high-temperature dyeing with sodium carbonate.

Spanish scientists [15] propose reusing wastewater from textile and dyeing production after pre-purification using Hydracore10 and Hydracore50 nanofiltration membranes. Decolorized and treated effluents were reused in new dyeing processes. Specialists evaluated dyed fabrics based on their original coloration. Color differences were within the perceptual range.

Industrial wastewater is one of the by-products of textile dyeing and finishing technologies. This water type is directed into settling tanks within the technological process, conforming to specified production requirements and technical characteristics. The mentioned wastewater goes through the subsequent cleaning and discharges into the general city sewage system [16] to become average.

Concentrated wastewater (CW) is generated directly after the fabric dyeing from intermittent equipment due to volley discharges from dyeing baths. This water contains, on average, up to 50% of unused active dye molecules not adsorbed by the fabric. It was determined in the laboratory [17] that the average content of textile dyes in concentrated wastewater is as follows: disperse dyes – 39 % and active dyes – up to 45 %. Wastewater contains about 5–30 % of dye and a significant amount of electrolyte and alkali [18] when dyeing with direct coloring agents.

This formed the basis for proposing a hypothesis [17] regarding the reuse of coloring components (that are part of CW in the technological cycle of coloring and finishing production) to increase its economic efficiency and high profitability.

The objective of this study is to conduct experimental research on the possibility of reusing concentrated wastewater from dyeing cotton fabrics with Direct yellow light-resistant K dye while coloring; to develop a technology for cyclic utilization of concentrated wastewater based on experimental data; to create a schematic diagram illustrating the repeated use of concentrated wastewater in cotton fabric dyeing technology.

Materials and methods

Actual concentrated wastewater from the dyeing and finishing production of the Private Joint Stock Company Cherkasy Silk Plant (PJSC CSP) (Cherkasy, Ukraine) was chosen as the subject of the study. The wastewater was collected immediately after dyeing cotton fabrics with direct dyes using periodic equipment, resulting in volley discharges.

Samples of the technological coloring solution and the obtained CW after the dyeing with Direct yellow light-resistant K dye were studied (Fig. 1).

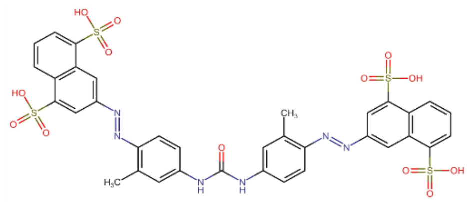

Fig. 1. Molecular formula of Direct yellow light-resistant K dye 3-[[4-[[4-[(4,8-disulfonaphthalen-2-yl) diazenyl]-3-methylphenyl] carbamoylamino]-2-methylphenyl] diazenyl] naphthalene-1,5-disulfonic acid [19]

The coloring agent belongs to disazo dyes with disconnected azo groups, in which the carbodiimide group acts as a disconnecting agent. It's possible to get these dyes by acylating monoazo coloring agents containing amino groups with dichloride of carbonic acid (phosgene). As a result of the reaction, the dye molecule doubles due to the binding of two molecules through the carbodiimide group. This increases the dye's affinity to the fiber and imparts direct dye properties. Such coloring agents are also called phosgenated. Such dyes are resistant to light and wet treatments. Direct dyes are commonly used to color plant and animal-origin fibers in neutral or weakly alkaline environments. The advantages of coloring with direct dyes include ease of use, low price, color brightness, excellent color transfer, solubility in water, and the possibility of combining with other types of dyes [20].

Coarse calico and viscose fabrics were dyed under production conditions at the PJSC CSP (Cherkasy, Ukraine). Coarse calico is a dense cotton fabric with a linen weave. It is made entirely of cotton, offering high density and cost-effectiveness. This fabric is characterized by high hygroscopicity, wear resistance, environmental friendliness, hygiene, and strength (density is 145 g per 1 m^2 of fabric) and it does not accumulate static electricity [21; 22]. We used the Coarse calico fabric (art. 3461) produced by the Private Joint Stock Company Cherkasy Silk Plant (PJSC CSP) (Cherkasy, Ukraine).

Journal of Chemistry and Technologies, 2024, *32*(4), 1119-1128

Viscose is a fabric obtained artificially from natural raw materials. The chemical composition of viscose fibers is identical to cotton, but they have a much lower degree of polymerization. It consists of approximately 80 % α-cellulose and 20 % impurities. Viscose fiber is formed as a result of the xanthogenation. Wood cellulose is kept in a caustic soda (18 % NaOH solution), with subsequent carbon disulfide treatment, forming cellulose xanthogenate (cellulose-O-CSSNa). This results in a paste-like viscous mass, which is extruded through a textile spinneret into a water bath containing sulfuric acid, sodium sulfate, and zinc sulfate. The threads formed in this way are pulled out of the bath at a controlled rate with a certain degree of applied tension [23; 24]. Viscose is a weaker fiber than cotton. It has less abrasion resistance, lower heat resistance, lesser moisture resistance, and poorer thermal conductivity. However, this is the cheapest artificial fiber, easy to drape, and keeps you cool on hot days. It is often mixed with cotton, nylon, polyester, or wool [25]. We used the Viscose fabric (art. 3324) produced by PJSC CSP.

Fabric samples were dyed on the AHIBA NUANCE CH-6015 (Datacolor, USA) laboratory machine in real production conditions of the PJSC CSP dyeing and finishing production according to the recipe that corresponds to the enterprise's technological regulations. The composition of the dye bath (technological dye solution) is given in Table 1.

Table 1

The composition (recipe) of the dyeing bath (for a total volume of 0.08dm^3) according to the regulation of the PJSC CSP's coloring and finishing production

№	Name of the component	Element weight, g
1.	Washing soda (sodium carbonate, Na_2CO_3 GOST 32802-2014)	2
2.	Table salt (sodium chloride NaCl GOST 4233-77)	3
3.	Previously boiled dye solution (3%)	12
4.	Softened water (softening is carried out at PJSC CSP)	63

The cotton fabric coloring with direct dyes is performed in a neutral environment. However, since the solubility of dyes improves in an alkaline environment, sodium carbonate Na_2CO_3 is added to the dyeing bath as an alkaline reagent. Washing soda enhances dye dissolution and creates a slightly alkaline environment (pH 8–10), which improves the interaction between the dye and the fiber by increasing fiber swelling.

Introducing a neutral electrolyte into the dyeing bath significantly affects the transfer of direct dyes from the solution to the cellulose fiber. Electrolytes (sodium chloride) improve dye pick-up by the fiber. The electrolyte input reduces the fiber's electrical potential and promotes the sorption of dye anions on the fabric's surface. At the same time, the electrolyte promotes the aggregation of dye molecules that cannot directly participate in the dyeing process. This results in a reduction of dye quantity absorbed by the fiber. Therefore, the amount of electrolytes in the bath must be strictly controlled. The consequence of this is a faster and more complete transition of the dye to the fiber, which increases its intensity and causes less contamination of wastewater with coloring agents.

The fabric dyeing processing method is carried out in the following sequence:

- Dip 2 g of cotton and 2 g of viscose fabric into the dye solutions.
- It takes 40 minutes at a temperature of 95 °C in a periodic manner for successful coloring.
- Wash samples several times with tap water.
- Drain off fabric samples in a drying cabinet at a temperature of 100 °C for 5–7 minutes.
- Examine dyed samples to assess color intensity and stability.

Since used CW contains significant amounts of dyes and auxiliary substances, the recipe for dyeing cotton fabric considers the dye content in wastewater. The potentiometric method was used to perform qualitative and quantitative analysis of dye solutions and the resulting wastewater using a Metrohm 744 pH meter. A photocolorimetric method, utilizing a UV-5800 PC (China) spectrophotometer, was employed to conduct qualitative and quantitative analyses of dyeing solutions and produced wastewater. Additionally, it was used to determine the residual dye mass in CW. The color characteristics of the examined tissue samples were determined using a Datacolor Spectrum 400 (Datacolor USA) in the CIELAB color system.

The quality and stability of the obtained colors were assessed by comparing them with the standards used for samples at PJSC CSP and by determining the stability of dyeing under the current state standards of Ukraine (DSTU ISO 3998-2000 [26], DSTU ISO 105-X12:2016 [27], DSTU ISO 105-A02:2005 [28], DSTU EN ISO 105-

Journal of Chemistry and Technologies, 2024, *32*(4), 1119-1128

C10:2020 [29]. The Stainingtester device (Computex, Hungary) was used to measure color fastness to dry and wet crocking according to DSTU ISO 105-X12:2016. This test involves the device's head, covered with white cotton fabric, making ten back-and-forth movements on a 10cm-long fabric sample under a load of 9H. At least three samples were tested, and the arithmetic average of all measurements was calculated as the result.

Results and discussion

The density and pH of dyeing solutions affect the dye adsorption by fiber. Physicochemical analysis of the dyeing solutions' density and pH, as well as the resulting CW, was conducted to determine optimal coloring conditions. The results are presented in Table 2.

Table 2

Values of pH and density of the studied water systems when colored with Direct yellow light-resistant K dye

Fabric	pH		Density, g/cm^3	
	technological solution dye	concentrated wastewater	technological solution dye	concentrated wastewater
Coarse calico (art. 3461)	9.97	9.90	1.002	1.004
Viscose (art. 3324)	10.13	10.08	1.002	1.001

The values in Table 2 show that only a certain amount of dye must be added to wastewater to create a new technological solution based on CW. This will determine the optimal conditions for dye sorption by the fiber and the concentration of coloring agents in the dyeing solution based on technological parameters.

Since the color of the dye depends on its interaction with light, the quantitative content of the colorant in the investigated solutions was determined using the spectrophotometry method with subsequent mathematical calculations (Fig. 2). Photometric analysis was performed with a UV-5800PC spectrophotometer.

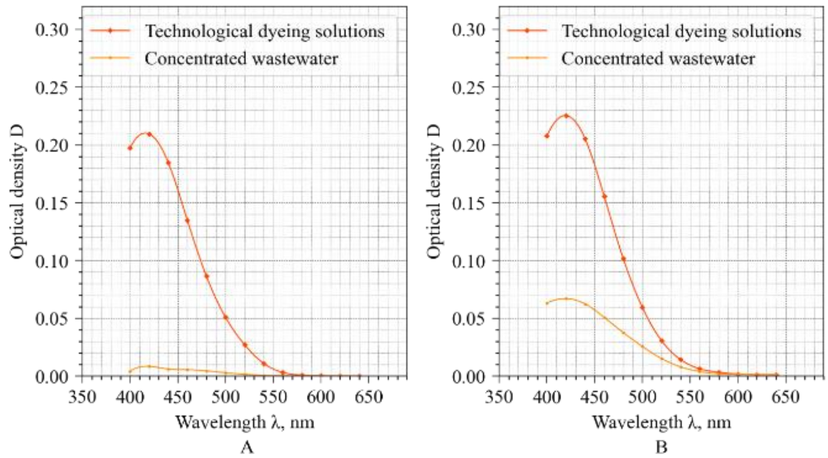

Fig. 2. Optical spectra of aqueous solutions absorption with the Direct yellow light-resistant K dye: A – Coarse calico fabric (art. 3461), B – Viscose fabric (art. 3324)

We mathematically calculated concentrations and masses of the dye in the investigated water systems. The results of these calculations, the direct dye content in the dyeing bath (in the technological solution), and the formed CW are presented in Table 3.

Table 3

The content of the Direct yellow light-resistant K dye in the technological staining solution and CW (solution per volume of 0.08dm^3)

Fabric	Dye concentration in the technological dyeing solution, (mol/dm^3)	Dye concentration in CW, (mol/dm^3)
Coarse calico (art. 3461)	$8.64 \cdot 10^{-4}$	$0{,}334 \cdot 10^{-4}$
Viscose (art. 3324)	$8.64 \cdot 10^{-4}$	$2.57 \cdot 10^{-4}$

The hypothesis was tested by coloring cotton fabrics in real production conditions using new dyeing technological solutions with the laboratory machine AHIBA NUANCE CH-6015 (Datacolor, USA). The formulation for the new coloring solutions was calculated mathematically. It comprises a 3% pre-boiled Direct dye solution (in accordance with the technological mode of PJSC

CSP) and CW added to the total capacity of the laboratory dyeing machine. The composition of new technological solutions is given in Table 4.

Table 4

Formulation of the created dyeing technological solution using CW

Fabric	Volume of dyeing solution (3% pre-boiled) that must be added to concentrated wastewater, dm^3	Volume of concentrated wastewater, dm^3	Total volume of coloring solution, dm^3
Coarse calico (art. 3461)	$11.6 \cdot 10^{-3}$	$68.4 \cdot 10^{-3}$	$80 \cdot 10^{-3}$
Viscose (art. 3324)	$8.4 \cdot 10^{-3}$	$71.6 \cdot 10^{-3}$	$80 \cdot 10^{-3}$

The quality of the obtained colors was determined by the characteristics indicators guided by the CIELAB color system. This color space is standardized by the International Commission on Illumination (CIE). It is used for color control and determining its differences (delta, D) according to a known standard (lightness, intensity of red/green, and yellow/blue hues), using a standard and a test sample for color comparison. The fabric's color can be objectively described by a set of hue coordinates, which can be obtained through non-destructive spectrophotometric measurements of the sample under investigation. The CIELAB color space is a three-dimensional Cartesian space with three mutually perpendicular color coordinates: L* – correlates with the perceived lightness; a – axis represents the red (a > 0), green (a < 0) regions; and b – axis represents the yellow (b > 0), blue (b < 0) – regions of chromatic coordinate [30]. The system allows the comparison of colors due to the system of color coordinates and the associated diagrams.

Samples dyed according to the PJSC CSP's basic technology served as standard (reference) examples of cotton fabrics. Samples dyed using CW were investigated. The color characteristics were determined using an automatic computer system of objective color measurement Datacolor Spectrum 400 (Datacolor USA). Its principle is based on measuring the spectral composition of the light reflected by the sample and calculating, based on it, color coordinates in the CIELAB color space.

Determining the indicators is straightforward. The color of the sample under investigation is analyzed in the CIELAB system and compared to the production color standard. The color difference between the sample under research and the standard is calculated, and then compared with the acceptable limits for the colored product consumer. Acceptable limits are established based on the color quality requirements set by the customer and fulfilled by the production process to produce the finished product [31, P.2].

The acceptable tolerances for samples investigated by PJSC CSP, compared to reference standards, allow for deviations in color intensity of up to 5 %, lightness (DL), and shades of DA (red-green) and DB (yellow-blue) up to ± 2.

The color characteristics of the investigated samples are provided in Table 5.

Table 5

Color characteristics of fabrics stained with Direct dye yellow light-resistant K dye compared to the basic technology of PJSC CSP

Fabric	Lightness DL	Hue (red-green) DA	Hue (yellow-blue) DB	Color difference DE*	Color intensity, % according to the standard (100%)
Coarse calico (art. 3461)	+0.43 lighter	+0.85 redder	+1.1 yellower	1.78	**95.7**
Viscose (art. 3324)	+0.48 lighter	+1.62 redder	+1.47 yellower	1.89	**95.2**

* Color difference is a mathematical representation that makes it easy to express the difference between two colors in colorimetry numerically. DE should not exceed 2, corresponding to the minimally noticeable difference between colors for the human eye [32].

Therefore, the quality indicators and the color intensity of cotton fabrics dyed with Direct yellow light-resistant K dye fall within the acceptable tolerance limits set by PJSC CSP. Specifically, the color intensity ranges from 95 % to 96 %, the color difference does not exceed 2, and the differences in lightness and shade between the reference and investigated samples are within ± 2.

Samples of dyed fabrics are shown in Figure 3.

Journal of Chemistry and Technologies, 2024, *32*(4), 1119-1128

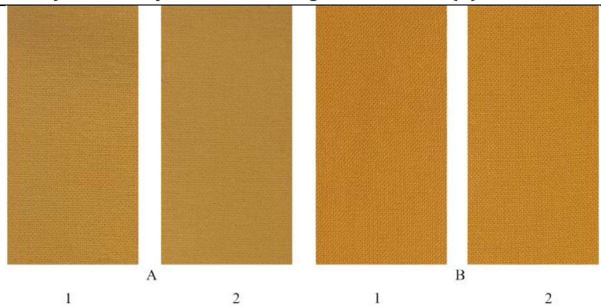

Fig. 3. Samples of cotton fabric dyed with Direct yellow light-resistant K dye: A – Coarse calico fabric (art. 3461), B – Viscose fabric (art. 3324): 1 – technological solution according to the basic PJSC CSP recipe, 2 – created technological solution using CW

Qualitative indicators of dyed fabric samples' color fastness were studied by DSTU ISO 105-A02:2005 Gray standards scale, in particular, indicators of color fastness to dry and wet crocking (DSTU ISO 105-X12:2016) and the influence of soap (DSTU EN ISO 105-C10: 2020) (Table 6).

Table 6

Qualitative indicators of dyed fabric samples' color fastness

Fabric	Technological dying solution	Dry friction, points	Wet friction, points	Influence of soap, points
Coarse calico (art. 3461)	PJSC CSP	4	2	3
	technological solution with CW	4	2	4
Viscose (art. 3324)	PJSC CSP	3	2-3	3-4
	technological solution with CW	3	2-3	3-4

As a result, the quality characteristics of fabric samples colored using the developed dyeing technological solution with CW align with those of samples dyed according to PJSC CSP's basic recipe.

Drawing from these and prior studies [33–35], which describe the results of the study of the process of dyeing cotton fabrics with Direct Fast Blue B2RL and Direct Red Light-resistant dyes using wastewater, a fundamental technological diagram of the fabric dyeing process was established. This diagram incorporates periodic reuse of CW for the first time (see Fig. 4). Dyeing according to this scheme has been tested in the PJSC CSP's production conditions in automatic dyeing-roller machines of periodic action Jigger VN (Henriksen Company, Denmark) and has practically significant results.

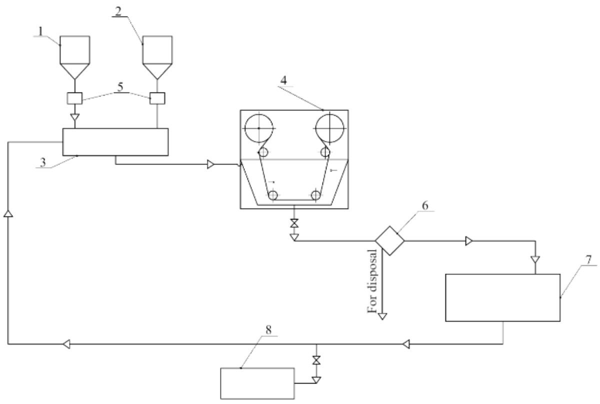

Fig. 4. Schematic diagram of the dyeing cotton fabric's technology in a periodic way with repeated use of dyeing and finishing production's CW: 1 – tank with process water; 2 – container with dye and auxiliary substances; 3 – the reactor for the dyeing solution preparation; 4 – roller dyeing machine (jigger); 5 – dispensers; 6 – mechanical pre-cleaning filter, 7 – collector of concentrated wastewater; 8 – general block of wastewater analysis.

The method of cotton fabric dyeing periodically with repeated CW dyeing and finishing production according to this scheme is as follows. Process water from tank 1 and dye with auxiliary substances from tank 2 are mixed in the dyeing solution preparation reactor 3, which is fed to the roller dyeing machine (jigger) 4, where the fabric dyeing process takes place. Dosers 5 are used to

Journal of Chemistry and Technologies, 2024, *32*(4), 1119-1128

meter out dye and other substances. Wastewater, after dyeing, gets a mechanical pre-cleaning filter 6, where mechanical inclusions (fluff, fabric threads, etc.) are retained, and the liquid is fed into the wastewater collector 7. Once in the general wastewater analysis unit 8, wastewater samples are taken and subjected to physical and chemical analysis (pH is determined using potentiometric method, dye concentration in wastewater is determined using spectrophotometric method, density of solutions is determined using an areometer).

After analysis and calculation of the amount of dyes and auxiliary substances in the wastewater, water is fed back into reactor 3. Then there's the preparation of a new dyeing solution, into which the amount of dye and auxiliary substances (as needed) that must be added based on the results of the physicochemical analysis is added from container 2 with wastewater (according to the recipe).

A single cyclic use of the CW was conducted while dyeing cotton fabrics with the Direct yellow light-resistant dye K during the experimental investigations. This fully corresponds to the experimental plan.

The cost savings associated with the dye were calculated to assess the feasibility of the new technology. The mathematical calculation was carried out by comparing the cost (in $) of the direct dye expenses according to the PJSC CSP's production recipe and a new one per 1200 running meters (RMTs) of fabric, such as a discontinuous roller dyeing machine Jigger (Vald Henriksen, Netherlands) dyes 1200 running meters (RMTs) during one stage (pass). The results of mathematical calculations are presented in Table 7 and shown in Figure 5. Dye costs were calculated using prices from August 2023.

Table 7

Savings in the use of Direct yellow light-resistant K dye when coloring cotton fabrics with CW

Fabric	Technological coloring solution	The cost of dyes, $/1200 RMTs of fabrics	Dyes cost efficiency, $/1200 RMTs of fabrics	Dyes cost efficiency, %
Coarse calico (art. 3461)	according to the basic recipe	91.33	4.5	4.93
	according to the new recipe with CW	86.83		
Viscose (art. 3324)	according to the basic recipe	89.85	15.3	17.02
	according to the new recipe with CW	74.55		

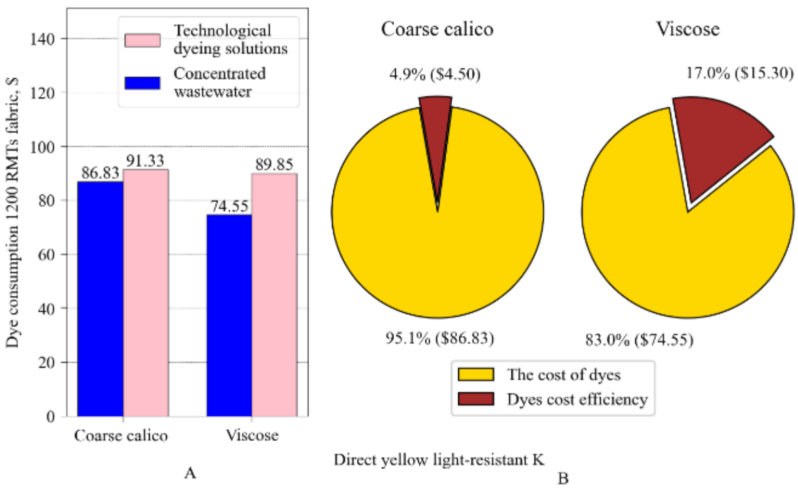

Fig. 5. Dye consumption savings of Direct yellow lightfast K in the dyeing technology using concentrated wastewater for every 1200m of cotton fabric: A - cost of dye consumption; B - dye consumption savings (in %) compared to the baseline technology

The average cost savings of Direct yellow light-resistant K dye is 11 % for every 1200 running meters (RMTs) of cotton fabric.

Conclusions

It has been experimentally proven for the first

Journal of Chemistry and Technologies, 2024, *32*(4), 1119-1128

time that concentrated wastewater obtained directly after dyeing cotton fabrics with Direct yellow light-resistant K dye from periodic equipment due to volley of dyeing baths sewage can be utilized as a secondary resource in the technology of coloring cotton fabrics.

Practical investigation has shown that adding a specific amount of dye to the concentrated wastewater, while maintaining constant values of density and pH, converts it into the technological dyeing solution. This will also help to ensure the parameters of the optimal conditions for dye sorption by the fiber and the concentration of the coloring agents in the dyeing solution.

As cotton fabrics were monochrome-colored with Direct yellow light-resistant dye K, we have experimentally determined the color characteristics of dyed fabric samples. A comparison between samples dyed according to the basic technology and those using concentrated wastewater has demonstrated that samples dyed using CW exhibited a color intensity of 95-96% compared to the standard (100%), the color difference between the reference and test samples DE is < 2, the difference in lightness and shades between the reference and test samples falls within ± 2, quality indicators of color fastness are 3-4 points according to the Grey standards scale, which is within the PJSC CSP's tolerance of acceptability. This proves the effectiveness of cotton fabric dyeing with Direct yellow light-resistant K dye with repeated use of CW.

A pioneering diagram for dyeing cotton fabrics with direct coloring agents, incorporating the reuse of concentrated wastewater, has been developed for the first time. Testing this dyeing scheme under industrial conditions at PJSC CSP has yielded significant practical results.

Research findings indicate that utilizing CW for monochrome dyeing with direct dyes could reduce their consumption by an average of 11% for every 1200 running meters (RMTs) of fabric.

A novel resource-saving technology for dyeing textile materials has been developed, based on the repeated (cyclical) use of concentrated wastewater during the dyeing process of cotton fabrics with direct coloring agents

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