Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2018.22401

114 (2018) 73–80
May

Designing a process flow diagram of wastewater treatment

Farida Rustembekovna Zhandauletova[a,*], Toty Sabirovna Sanatova[a],
Asel Amangeldievna Abikenova[a], Kairat Gabbasovich Mustafin[a],
Turkestan Saidahmetovich Baipakbayev[b], Svetlana Evgenievna Mananbaeva[a]

[a]*Department of Safety of Work and Engineering Ecology, The Almaty University of Energy and Communications, 126 Baytursynova Str., Almaty 050013, Kazakhstan, emails: zhandauletova.farida@gmail.com, zhrfarida@mail.ru (F.R. Zhandauletova), toty.sanatova@mail.ru (T.S. Sanatova), abikenova.asel@mail.ru (A.A. Abikenova), marat_mustafin@mail.ru (K.G. Mustafin), mananbaeva.svetlana@yandex.ua (S.E. Mananbaeva)*

[b]*Physics Department, The Almaty University of Energy and Communications, 126 Baytursynova Str., Almaty 050013, Kazakhstan, email: turkestan.baipakbayev@mail.ru*

Received 6 July 2017; Accepted 25 April 2018

ABSTRACT

This study provides a new innovative wastewater treatment technology and process flow diagrams of industrial wastewater treatment based on developed technology. These process flow diagrams allow discharging industrial wastewater into the city sewage network and recycling water supply of textile facilities. In general, up to 95% of all wastewater can be reused. Our process flow charts of wastewater treatment and obtained results of experimental studies can be used in designing new and modernizing the existing treatment facilities, as well as in analyzing the wastewater treatment technologies used in worsted and cloth industrial facilities.

Keywords: Wastewater; Advanced treatment; Regeneration; Sorption; Coagulant; Activated carbon

1. Introduction

Nowadays, industrial textile facilities are a formidable source of environmental pollution, primarily surface water and groundwater pollution.

Manufacturing, agricultural, fuel and power, and utilities industries development is associated with the consumption of large volumes of pure water and subsequent wastewater discharge. The quality of treated water discharged into waterways and the state of waterbodies that meet sanitary requirements is decreasing constantly. Typical wastewater pollutants that are generated by dyeing and finishing textile facilities include dyes, synthetic surface-active agents, suspended solids, and finishing materials.

The current global output of dyes is about 850.000 tons per annum, while the assortment of the most common ones feature's about 3,200 items. An area, where dyes are used widely, is the dyeing and finishing textile industry. The average daily volume of wastewater that is generated by textile facilities reaches 10.000 m^3 and varies radically in terms of its composition within a single facility based on the dyeing liquor and technology used in each specific case [1,2].

Advanced wastewater treatment and conditioning as well as removal of valuable products therefrom are important problems solved through the creation of simple, reliable, and cheap textile industry wastewater treatment technologies based on chemical methods and biological application [3,4].

Extracting the maximum possible amount of valuable products to recycle and reuse them in the industrial water supply system is one of the important principles in modern approach to wastewater treatment. Thus, water pollution and a negative impact on the environment are prevented while the problem of water resource protection and rational use is solved.

---

* Corresponding author.

1944-3994/1944-3986

Therefore, the problem of wastewater treatment and reuse is especially relevant for textile facilities located in the arid zone of Kazakhstan, which is exposed to significant water shortage.

All dyes that are used in the textile industry are electrolytes. In aqueous solutions, they split into negative and positive ions. It was discovered that dye salts and ions in solutions could be bound into more or less coarse aggregates. The size of dye particles usually depends on the temperature and the concentrations of electrolytes in the solution. Designing new wastewater treatment techniques based on physical and chemical methods in combination with biological treatment and removal of pollutants is a relevant problem [1–4].

Wastewater is polluted by dyes and synthetic surface-active agents (SSAA) from the dyeing and finishing sections of textile facilities [5–8].

According to theories [9] and researchers [10–14], dye solutions are complex substances that consist of ions, colloidal electrolyte molecules, and colloidal particles, which are in a state of dynamic equilibrium.

Colloidal and dissolved pollutants can be extracted therefrom by adding coagulants into water, namely – through physical and chemical processes that occur during the formation of extended surface of flakes that absorb pollutants [15]. The hydrolysis of coagulants dissolved in wastewater separates coarse aluminum and iron oxides with a significant specific surface of 100–400 m^2/g [16–18].

Thus, the purpose of this study is to design and prove scientifically a wastewater treatment process flow diagram that enables discharging industrial wastewater into the city sewage network and recycling water supply of textile facilities through ozone treatment and ion exchange.

Research objective is to study the effectiveness of wastewater treatment process flow diagram that uses coagulants and flocculation agents (aluminum and ferrous sulfates) and enables discharging wastewater into the city sewage network with a reduced chemical oxygen demand (COD), SSAA count, and content of chromium and dyes, and combines ozone treatment and ion exchange while recycling water supply system of textile facilities.

2. Methods and materials

Worsted wool fabrics enterprises use about 70% of water for major production purposes, about 23.5% – for auxiliary production purposes, and 6.5% – for household needs.

Major production purposes of the enterprise include dyeing-and-finishing costs. Water used for these purposes is of drinking quality. Compressor equipment operates on recycled water when freshwater used in repairing facilities and charging stations. The air blower station uses recycled water. Water treatment stations use drinking water for their own needs. Refrigeration stations require a large amount of drinking water for summer operation. They use the feed water recirculation cycles to cover irreversible losses. At the enterprise, water also used for household needs: in dining rooms and showers, for air conditioning and watering, and in the boiler room. Water recirculation, as a rule, used by equipment cooling systems.

The public waterworks system is a source of industrial water supply. The plant is also equipped with household, potable and fire-fighting water pipes. The process of fabric finishing requires clarified, cold and hot softened water. Process water softened at the chemical water treatment plant. Table 1 shows the physicochemical composition of the clarified and softened water used in dyeing and finishing industry.

The greatest amount of water goes for fiber dyeing and fabric wet finishing.

Dyeing and finishing stages end with wastewater, whose composition is complex and variable – waste solutions, alkaline and acidic wastes, dyes and intensely colored wastes, hot and cold ones, characterized by considerable color and toxicity, as well as by predominant content of dissolved organic matter determined by dyeing, washing, carbonization, welding and finishing technologies; as well as by dyeing and finishing solutions.

The greatest amount of wastewater (about 70%) discharged into the sewage network of the plant in the finishing shop. Such wastewater (Q = 5,975 m^3/d) is characterized by the following indicators: pH, 6.5–8.9; SS, 60–180 mg/L, COD, 180–500 mg O_2/L; SSAA, 5.8–30 mg/L, chromium, 0.1–1.2 mg/L. Such indices are determined by the presence of hydrolysis products, short fiber, wool fat, sizing agents, waste, used reagents, etc. Finishing wastewater is unstable in terms of its chemical composition. Industrial wastes are highly polluted during the fabric finishing. However, pollution level will be sharply reduced after machine washing.

A significant amount of wastewater formed by the dyeing-and-finishing shop and in the chemical station. It (Q = 3,143 m^3/d) is characterized by the following indicators: pH, 7–9.8; SS, 130–280 mg/L; COD, 500–804 mg O_2/L; SSAA, 26.2–86 mg/L, chromium, 2.4–5.2 mg/L.

According to the process technology, fabrics are being dyed by artificial organic dyes (acidic, chromic, active, etc.) with treating reagents: sodium and Glauber's salts, acetic and sulfuric acids, turpentine, SSAA.

Chromium and copper salts are used to fix the dyes. Consequently, the major components polluting wastewater in the dyeing shop are organic substances, chrome, oil products, mineral oils, detergents and fats. Washing is the most water-intensive operation. At the same time, dyeing waters, which amount is lower, has the highest level of pollution, while the water used for washing (over 75% of total process water used) is less polluted.

Table 1
Physicochemical composition of clarified and softened water used in dyeing-and-finishing industry

Indicators	Water	
	Clarified	Softened
Suspended substances (SS)	5	–
pH	6.5–8	8–8.4
Solid residue, mg/L	256	143
Ignited residue, mg/L	219	112
Loss on ignition, mg/L	37	31
Carbonate hardness, mg-eq/L	4	0.4–0.5
Alkalinity, mg-eq/L	3.6–3.8	0.4–0.7
Iron salts, mg-eq/L	0.1	<0.1

Physicochemical composition of dyeing and finishing wastewaters by shops and from the common drain presented in Table 2.

As the process equipment has different discharge time for wastewaters with various compositions, wastewater inflow, concentration and temperature balances are improper. The plant operates with a batch and continuous process equipment. Volley discharges are made mainly because of the steep boxes and foulard-dyeing machines have to be cleaned. In this regard, hour odds of uneven discharge range from 1.1 to 2.0, sometimes reaching 3.5.

Specific wastewater pollution involves dyes and SSAA.

The amount of used dyes range from 190 to 250 tons/year; the amount of SSAA is 90–150 tons/year.

Specific amount of dyeing and finishing wastewater generated at the plant with the once-through water-supply system is about 480–510 m^3 per 1 ton of fabric.

We have considered a separate sewerage system and a system of local dyeing and finishing wastewater treatment to choose an effective process flow diagram of wastewater treatment, as the combined treatment will not provide a required degree of purification due to various pollutants present in the wastewaters.

Thus, dyeing and finishing wastewaters are divided into two streams according to the nature of pollution and its concentration: washing water (slightly polluted) and concentrated water (heavily polluted). In addition, this division is supported by the existing plan of water discharge at the plant.

Flotation wastewater treatment was studied with a pressure-head flotation plant operator. Wash and concentrated wastewater streams were subjected to treatment. Washing wastewater was effectively treated by reagent dissolved-air flotation (DAF): SSAA and suspended substances (SS) were removed and its color intensity has significantly decreased. Table 3 presents the characteristics of separate dyeing and finishing wastewater streams.

At the flotation duration of 25–30 min, wastewater treatment is effective when it comes to removing SSAA (at 35%–65%), SS (at 40%–60%), COD (at 28%–40%), and decreasing color intensity (at 65%–75%).

At the aluminum sulfate dose (AI_2O_3) of 100–200 mg/L, concentrated wastewater is treated by reagent DAF. At the flotation duration of 30–40 min, wastewater treatment is effective when it comes removing SSAA (at 42%–68%), dyes (at 45%–70%), SS (at 70%), and COD (at 30%–40%).

In a dissolved air (pressure) flotation facility, air is dissolved into the water under pressure in pressure tanks.

We have studied the process of removing SSAA and dyes from washing and concentrated wastewater streams with a DAF unit in order to study how the final effect depends on the initial oversaturation degree of water, under the air saturation pressure of 0.2–0.5 MPa. Water saturation with air has lasted about 3–5 min. The air throttling was carried out with a needle valve directly before the water was delivered to the flotation tank.

According to experimental studies, we will get the highest level of treatment efficiency if the pressure, under which the air is dissolved in washing and concentrated wastewater, is 0.25–0.35 MPa and 0.3–0.4 MPa, respectively.

Table 3
Classification of wastewater generated by the dyeing and finishing facility

Indicators	Stream	
	Wash water	Concentrated water
Suspended substances, mg/L	60–180	130–280
COD, mgO$_2$/L	180–500	500–804
Solid residue, mg/L	800–1,300	1,200–1,800
SSAA, mg/L	5.8–30	26.2–86
Color intensity	1:50–1:110	1:130–1:280
Chromium, mg/L	0.1–1.2	2.4–5.2
pH	6.5–8.9	7–9.8

Table 2
Physicochemical composition of dyeing and finishing wastewaters (Kustanay worsted wool fabrics plant)

Indicators	Operation		Equalization tank	Common drain
	Finishing	Dyeing		
1	2	3	4	5
pH	6.5–8.9	6–9.8	7.4–11.2	6.8–10.0
Suspended substances, mg/L	65–180	130–280	100–220	90–240
Solid residue, mg/L	800–1,300	1,200–1,800	800–2,500	800–1,600
COD, mgO$_2$/L	180–520	500–850	280–700	240–650
BOD, mgO$_2$/L	96–160	240–370	125–450	120–340
Color intensity	1:50–1:110	1:130–1:280	1:110–1:190	1:80–1:200
Chromium, mg/L	0.1–1.8	1.4–5.2	0.4–1.6	0.2–2.3
Ammonia nitrogen, mg/L	18–20	15–26	8–15	9–18
Chlorides, mg/L	67–120	86–235	90–210	120–190
Sulfates, mg/L	220–520	233–700	120–420	100–350
SSAA, mg/L	5.8–30	26.2–86	18–57.4	6.2–46
Phosphates, mg/L	7–8	4–10	3.8–8	3–7

In treating wash water, we have used a direct-flow scheme of DAF. In this case, we have saturated with air the entire volume of treated water. In treating concentrated wastewater stream, we have used a recycle-flow scheme of DAF. The optimum recirculation rate was 50% of the wastewater flow rate. Reagent DAF was used in washing and concentrated wastewater treatment in order to remove SSAA, dyes, and SS.

If the advanced wastewater treatment is carried out with the adsorption method, the level of SS should not exceed 5 mg/L before water is supplied to adsorption filters.

The advanced wastewater treatment, focused on removing SS, was carried out with a granular filter. We have considered quartz sand as a load material. Experimental studies of such advanced wastewater treatment were conducted with a filter column, which was part of a pilot unit.

Wastewater was under advanced treatment at a constant hydrostatic pressure (8–10 mp/h). The level of SS has decreased by 87%–90.8% on average.

The advanced wastewater treatment was carried out with the adsorption method when the color intensity was 1:28–1:50 (15–20 mg/L), the level of SS, 5–8 mg/L, COD, from 420 to 580 mg O_3/L, the level of solid residue, 920–1,650 mg/L, and the level of SSAA, 12–16 mg/L. Wastewater requiring adsorption is a highly diluted solution of organic compounds. Colored wastewater adsorption was carried out in a column, which height is 3.5 m and diameter is 210 mm. The load height was 2.0–2.2 m, grain diameter (d_{eq}), 1–1.5 mm, average filtration rate, 5–6 m/h, cycle duration, 22–24 h, activated charcoal brand, AG-3.

After advanced treatment with the adsorption method, wastewater had the following characteristics: SS, 1–2 mg/L, SSAA, up to 1 mg/L, no dyes, COD, 50–2 mg O_2/L, solid residue, 850–1,480 mg/L. Dyeing and finishing wastewater was completely discolored after advanced treatment with activated carbon. Moreover, COD and biochemical oxygen demand (BOD_5) values were reduced by 80%–85% and 90%–98%, respectively, as well as the level of SSAA by 96%–100%.

We have selected AG-3 activated carbon to study the technological parameters of activated carbon regeneration. The AG-3 activated carbon included dyes, surface-active agents, and other substances, both in pure form and in the form of mixtures.

The technological study of thermal-oxidative regeneration of AG-3 activated carbon was conducted with a bench rig (Fig. 1).

In this rig, activated carbon with organic substances of a standardized test solution underwent thermal-oxidative regeneration with flue gases.

The temperature of flue gases was reduced to the set level by mixing them with moisture vapor that was supplied by the steam generator. The generated gas with an oxygen content of 2.5%–4.0% and temperature of 280°C–360°C passed through a layer of processed carbon, where the oxidation of adsorbed organic substances commenced and the carbon was heated to 450°C–600°C. The zone with high-temperature carbon was moved by the reactant gas to the lower layers, while the processed carbon was cooled to 200°C–350°C by an approach flow of steam, gas, and air. Processed activated carbon was heated until the adsorbed organic substances burned away completely. At that, an increase in oxygen concentration in the flue gas to 2.4%–3.8% volume fraction illustrates the completion of an adsorbed organic substance oxidation reaction.

The indices of regeneration with multiple uses of AG-3 activated carbon are presented in Table 4.

Physical and chemical characteristics of processed activated carbon show that the regeneration was complete and the sorbent was of high quality.

Sorption on the surface of oxides and the chemical interplay of pollutants with them largely depend on the degree of electrolytic dissociation of colloidal electrolytes and are affected by the pH level of the wastewater medium.

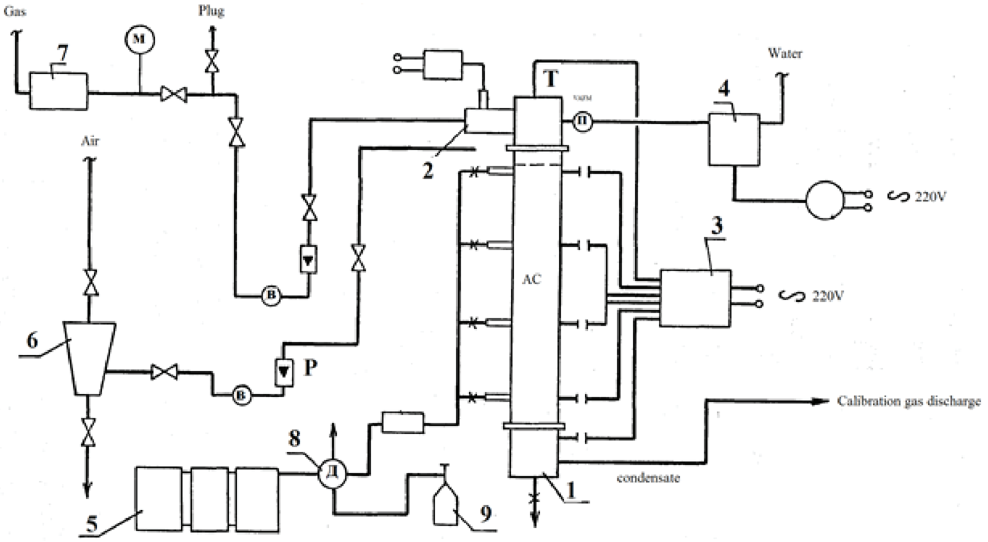

Fig. 1. Process flow diagram of the activated carbon regeneration rig. 1, Adsorption column; 2, fuel device; 3, KSP-4 potentiometer; 4, steam generator; 5, chromatograph; 6, receiver tank; 7, gas divider; 8, sample valve; 9, helium tank; VAFM, variable area flow meter; and M, manometer.

Table 4
Regeneration parameters of activated carbon saturated with organic substances of the standardized test solution

Regeneration number	Consumption rate, m^3/h			Gas mixing range, m/s	Oxygen content at the carbon layer entrance, volume %	Pressure above the carbon layer, mmH_2O	Temperature, °C	
	Natural gas	Air	Steam				Above the carbon layer	In carbon
1	0.28–0.33	3.09–3.60	2.10–2.40	0.46–0.51	0.1–4.0	300–1,150	320–360	85–600
2	0.29–0.35	2.95–3.70	2.40	0.45–0.53	0.1–3.8	425–1,410	305–360	85–595
3	0.29–0.32	2.95–3.65	2.40	0.46–0.53	0.1–4.1	400–1,200	290–350	85–620
4	0.27–0.32	3.00–3.70	2.40	0.47–0.47	0–3.7	550–1,600	260–380	85–550

2.1. Experiments with adsorption of organic pollution of wastewater from dyeing and finishing facilities with aluminum and iron oxides

When Al sulfate is added to water, it dissociates:

$$Al_2\,(SO_4)_3 \rightarrow 2Al^{3+} + 3SO_4^{\,2-} \qquad (1)$$

This is followed by the hydrolysis of excess aluminum sulfate and the formation of intermediate compounds – Al^{3+} and OH^- ions, which ends with the production of a colloid of a slightly soluble aluminum oxyhydrate sediment:

$$Al^{3+} + H_2O \rightarrow \downarrow Al(OH)_3 + 3H^+ \qquad (2)$$

In addition to forming aluminum oxides at wastewater pH 6.5–8.0, aluminum ions are partially used to form the colloid of Al hydroxide salt, which also generates a slightly soluble sediment:

$$Al^{3+} + SO_4^{\,2-} + 4H_2O \rightarrow \downarrow Al_2(OH)_4 + 4H^+ \qquad (3)$$

Hydrogen ions are removed via interaction with bicarbonate ions that are located in wastewater:

$$H + HCO_3^- \rightarrow CO_2 + H_2O \qquad (4)$$

The formation of iron oxides during ferrous sulfate hydrolysis occurs in a similar fashion.

Laboratory studies determined the optimal doses of aluminum sulfate for wastewater: 100–150 mg/L for rinse wastewater; 150–200 mg/L for concentrated wastewater.

Adding 1.5–2.5 mg/L of the polyacrylamide flocculation agent only reduced the sediment volume.

The use of iron-containing reagents only increases the coloring of wastewater.

In order to remove SSAA and suspended materials, wastewater from dyeing and finishing facilities were exposed to reactant DAF, during which the molecules and micelles of surface-active agents were adsorbed on the surface of oxyhydrates and surfaced into the foamy product.

The designed water treatment technology includes the breaking of foam with recycled water that was previously discharged into the sewer after lime neutralization.

A thin-layer sediment tank was used for the gravity settling of coagulated suspended material flakes. These sediment tanks reduce the sedimentation time to 15–20 min versus other tanks and take up less space, which enables installing them in indoors.

An effective method of advanced treatment of wastewater, with a view to removing dyes and SSAA, is the combination of ozone treatment and ion exchange.

Ozone has a high oxidizing capacity (E_o = 2.07 V; in an alkaline medium, E_o = 1.24 V) and disintegrates many organic substances in water at normal temperatures. Ozone treatment of water is accompanied by the oxidation of impurities, decoloring, odor removal, decontamination, and oxygenation of wastewater. The advantage of this method is that it does not use chemical reagents [19,20].

The solubility of ozone in water depends on the pH level and the amount of impurities in the water. In the presence of acids, the solubility of ozone in water increases, while in the presence of alkali it decreases. Ozone spontaneously degrades in air and water solution, transforming into oxygen. In a water solution, ozone degrades faster. The degradation of ozone in water increases rapidly as the pH level increases. The degradation rate of ozone increases with temperature. Ozone reacts with saturated compounds and forms free radicals.

Ozone oxidation of organic substances can proceed up to the formation of CO_2 or H_2O, but the consumption rate of ozone increases substantially at that. The suggestion is to use catalytic agents, such as copper oxide and silica gel, to accelerate the ozone oxidation of organic impurities in wastewater. During wastewater treatment, after ozone treatment, the COD reduces by 47%–68%, the coloring of wastewater by 69%–88%, and SSAA by 32%–48%.

Fig. 2 shows a dependency diagram of ozone concentration on air consumption Q (m^3/h) with constant current consumption I, discharge power D_p, and air pressure P.

Ozone treatment is an effective method of breaking surface-active agents, especially those that are resistant to biological oxidation. Ozone oxidation of surface-active agents creates products that are easily oxidized biologically.

Ozone oxidation of non-ionic surface-active substances – oxypolyethyl fatty acid (OP-10), ethoxylated fatty acid (EFA), and Dissolvan 4411 – contained in aqueous solutions was studied experimentally. At a concentration of 120 mg/L of OP-10 in water, optimal pH level 5, and exposure duration of 10 min, the amount of OP-10 reduced by 70%. At that, ozone consumption rate was 0.455 mg per 1 mg of OP-10.

The degree of EFA oxidation at an ozone consumption rate of 0.601 mg per 1 mg of EFA was 94% with 61.3 mg/L

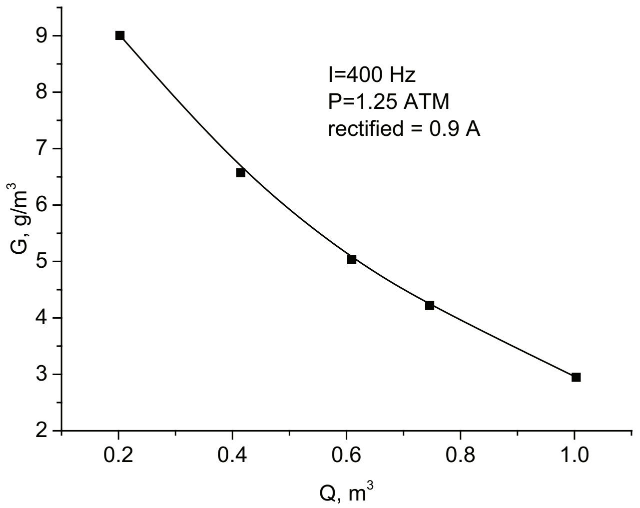

Fig. 2. Dependency of ozone concentration on air consumption with constant current consumption *I*, discharge power D_p, and air pressure *P*.

initial concentration of EFA in water and pH = 10.8. A higher degree of oxidation (96%) was achieved during ozone treatment of Dissolvan 4411.

This effect was achieved at pH = 7.8, 58.5 mg/L Dissolvan concentration in water, and ozone consumption rate of 1.269 per 1 mg of surface-active substance. The degree of oxidation of Dissolvan increased when the temperature was raised to 60°C with a simultaneous reduction of ozone consumption at that. The use of ozone treatment to decolorize dye-containing wastewater showed that the presence of a mixture of various dyes in the water in a concentration of 10/25 mg/L did not decelerate the decoloring process. The ozone consumption rate, the exposure duration, and the oxidation reaction speed depend on the chemical structure and concentration of dyes and SSAA.

When examining the kinetics of the ion-exchange process, it is necessary to take into account such factors as temperature, the exchange capacity of the ion exchange, structural peculiarities, etc.

Ion-exchange treatment of wastewater used artificial and natural mineral and organic cation exchangers. Mineral cation exchangers, despite their inexpensiveness, have failed to become widely used due to their poor exchange capacity and insufficient stability. Artificial organic strongly acidic (KU-1, KU-2, sulfated carbon, Wofatits, etc.) and slightly acidic (KB-4, SG-1, Amberlites, etc.) cation exchangers are used more frequently [21].

If cation exchangers are in H- or Na-form, cation exchange will occur according to the following reactions, respectively:

$$Me^+ + H[K] \rightarrow Me[K] + H^+ \quad (5)$$

$$Me^+ + Na[K] \rightarrow Me[K] + Na^+ \quad (6)$$

where [K] is the complex aggregate of the cation exchanger, Me^+ is the cation solution (wastewater).

When water is filtered through an H-cation-exchanger filter, H ions transfer to the water and anions transform into corresponding mineral acids. The dry residue of water shrinks at that. When using a Na-cation-exchanger filter, the alkalinity of water barely changes, while the content of the dry residue depends on the atomic weight and valence of the exchanged cation. Strongly acidic cation exchangers enable conducting the process in any medium, while slightly acidic cation exchangers – in alkaline and neutral media only.

Regeneration of the cation exchanger – reverse replacement of its adsorbed ions with hydrogen and sodium ions is achieved by washing the cation exchanger with acid treated (in the case of H-cation exchangers) or a common salt solution (in the case of Na-cation exchangers):

$$2Me[K] + H_2SO_4 \rightarrow 2H[K] + Me_2SO_4 \quad (7)$$

$$Me[K] + NaCl \rightarrow Na[K] + MeCl \quad (8)$$

Physical-and-chemical treatment favorably differs from the usual method of reagents due to its intensive separation of reagents and destruction of sodium chloride and chromium, which are commonly used in the dyeing and finishing technology. In addition to the disengagement of reagents during treatment, with a view to organizing a recycling water supply system, advanced treatment of wastewater to remove dyes and SSAA with a combined method that uses ozone treatment and ion exchange is expedient, since the resulting water can be returned into the technological process.

In other words, the use of physical and chemical treatment in combination with ozone treatment and ion exchange in the textile facility wastewater treatment technology opens a vast prospect of turning the dyeing and finishing technology into a low-waste or even non-waste one.

This analogy shows that the methods of textile facility wastewater treatment that are proposed in this study reproduce the natural conditions of self-treatment of waterbodies and are, therefore, the most expedient and rational ones.

3. Results and discussion

The hydrologic equilibrium calculations and the results of experimental studies were used to design a process flow diagram of preliminary treatment of textile facility wastewater.

The technology includes separate treatment of industrial wastewater in two flows: washing and concentrated. The wastewater was treated as follows: neutralization, dissolution of dissolved air by flotation, and thin-layer precipitation. The effectiveness of treatment in terms of color intensity depending on the dose of coagulant is presented in Fig. 3.

In order to reuse wastewater from dyeing and finishing facilities, the treatment process flow diagram includes granular filters that remove suspended particles. As a filler for filters using expanded clay and sand from a local quarry. The extended surface of expanded clay sand and high filtering capacity turned out to be significantly more effective than quartz sand filters. The use of crushed expanded clay increased the filtration rate by 1.5–2.0 times and reduced the consumption of water for filter washing. The filters were washed with treated wastewater.

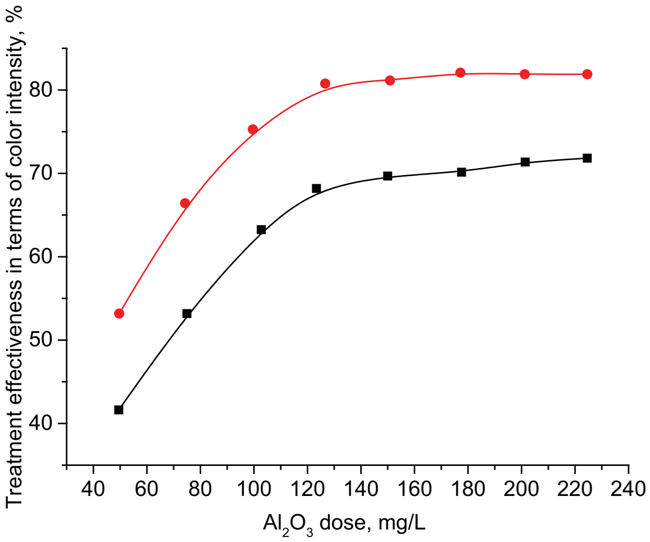

Fig. 3. Dependency of wastewater treatment effectiveness in terms of color intensity (%) on the coagulant dose (mg/L).

Table 5 shows the wastewater characteristics before and after treatment by reagent DAF at the aluminum sulfate dose (Al_2O_3) of 100–200 mg/L.

The diagram of suspended substance removal involves granular filters, designed to make dyeing and finishing wastewater suitable for reuse. Exclay and local pit sand were used as load material. Wastewater, treated in granular filters, is suitable for reuse during equipment cooling and hydrocleaning at the industrial facilities.

After treatment in granular filters, water is suitable for reuse in technological processes: equipment cooling, hydrocleaning of industrial facilities, etc.

Advanced water treatment to remove impurities was carried out by adsorption on activated carbon. The fillers used in adsorption filters were SK-3 sulfated carbon (0.3–1.5 mm grain size) or AG-3 activated carbon (0.5–2 mm grain size).

After the advanced treatment of wastewater in granular and adsorption filters, the coloring reduced by 96%–99%, the amount of suspended materials by 98%, COD by 78%–99%, SSAA by 89%–96%.

Kinetics of pollutant removal from concentrated wastewater by reagent DAF at an aluminum sulfate dose (Al_2O_3) of 150 mg/L is shown in Fig. 4.

Activated carbon was regenerated at a temperature of 250°C–300°C. The volume of formed flotation sludge in percentage of the treated water volume was as follows: 2.5–2.8 with DAF of washing wastewater; 3.5–4.0 with reactant DAF of concentrated wastewater. The initial humidity of the flotation sludge was 99.2%–99.5%. Flotation sludge was compacted for 12 h before dehydration. The humidity of the compacted sediment was 97%–98% versus the initial humidity of the flotation sludge was 99.2%–99.6%.

After studying the processing of dyeing and finishing facility wastewater sediments, the suggestion was to use pressure-type filters.

In comparison to vacuum filters, sediment dehydration in pressure-type filters requires less space and ensures lower cake humidity.

Table 5
Efficiency of dyeing and finishing wastewater treatment by reagent dissolved-air flotation with optimal doses of mineral coagulants

Indicators	Wastewater characteristics		Treatment efficiency, %
	Before treatment	After treatment	
1	2	3	4
pH	7.6	6.0	–
Suspended substances, mg/L	220	88	60
BOD, mgO$_2$/L	340	170	50
COD, mgO$_2$/L	700	427	39
Solid residue, mg/L	1,100	750	–
Color intensity	1:200	1:50	71
SSAA, mg/L	65	23	65
Chromium, mg/L	0.45	0.1	77

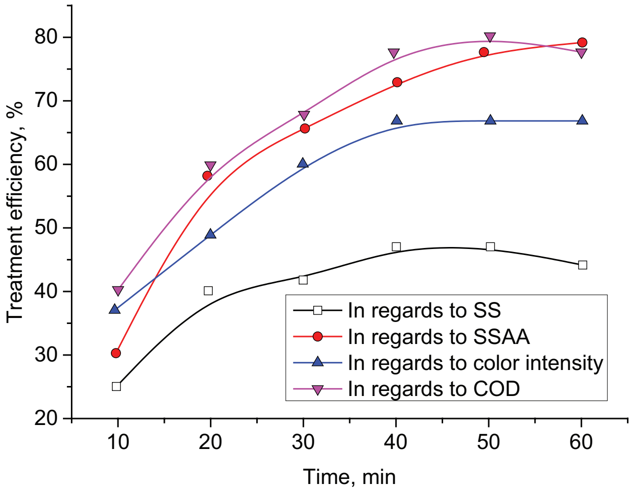

Fig. 4. Kinetics of pollutant removal from concentrated wastewater by reagent dissolved-air flotation at an aluminum sulfate dose.

Experimental studies showed that the load on the pressure-type filter was 7–9 kg/m^2·h. The sediment with 75%–80% humidity that was dehydrated in pressure-type filters was transported to city landfills.

Adsorption enables significantly reducing the concentration of dissolved mineral and ionized organic pollutants. When compared with other advanced treatment technique, the advantage of the sorption technique is that it decolorizes wastewater, removes a significant part of residual SSAA, and reduces salt content, which is especially important if the water should be reused in technological processes.

According to research results, the optimal dose of ozone was 10–20 mg/L, while the duration of wastewater exposure to the ozone-air mixture was 5–8 min. Waste degassing was included to remove excess ozone from wastewater. After ozone treatment, which included decoloring and oxidation, the water underwent ion-exchange advanced treatment.

The technological parameters of textile facility wastewater advanced treatment via ozone treatment and ion exchange were as follows: filtration – loading quartz sand with 0.8–3.0 mm fraction size into filters; loading height, 1.4 m; filtration cycle duration, 20–22 h; filtration rate, 8–10 m/h; supporting layers of loading – gravel with 5–20 mm fraction size, $h = 0.15$ and 0.3 m.

Ozone treatment: ozone consumption rate, 15–20 mg/L; duration of water exposure to ozone, 5–8 min; activated carbon filter, 1.5–2.7 mm fraction size or an expanded clay filter with 2–5 mm fraction size.

Ion exchange treatment: loading of SK-1 sulfated carbon with 3.3–1.6 mm grain size, loading height, 2.0 m, filtration rate, 5 m/h, filtration cycle duration, 12 h.

Adsorption treatment: loading AG-3 activated carbon with 1–1.5 mm fraction size, loading height, 2.0–2.2 m, filtration rate, 5 m/h, and filtration cycle duration, 24 h.

The physical and chemical composition of recycled water was used to create artificial models of recycled water: initial and recycled water after 15 cycles or 70% of the entire water cycle. In order to study the quality indices, fabric samples were treated with model recycled water and compared with the control sample that was treated with freshwater [17].

It is worth noting that multiple use of treated wastewater in recycling water supply system accompanied by an increase in water hardness, despite the supply of fresh industrial water.

In order to prevent salt accumulation, 30% of the daily consumption of recycled water was used to soften the ion-exchange filters and purge system. This improves the quality of recycled water.

4. Conclusion

The analysis of reagent DAF method application when treating dyeing and finishing wastewater shows that worsted and cloth industrial facility allows achieving a high treatment effect. Advanced treatment of wastewater enables reusing treated water as washing water. Fresh industrial water is required to produce dyeing and finishing solutions at that. The designed method of activated carbon regeneration restores the initial capacity of carbon almost entirely. In order to adjust the salt content of the reused water, 30% of system purging is required.

References

[1] Y.V. Voronov, S.V. Yakovlev, Waver Removal and Wastewater Treatment – M, Association of Educational Civil Engineering Institutions of Construction Publishing House, 2006, p. 704.

[2] A.G. Vetoshkin, Theoretical Basis of Environmental Protection, Penza, 2004, p. 249.

[3] N.A. Bazyakina, Cleaning of Concentrated Industrial Wastewater, Gosstroyizdat, Moscow, 1958, p. 245 (in Russian).

[4] D.A. Krivoshein, P.P. Kukin, V.L. Lapin, N.L. Ponomarev, N.I. Serdyuk, A.G. Fetesov, Engineering Protection of Surface Water from Industrial Waste, Vysshaya Shkola, Moscow, 2003.

[5] F.R. Zhandauletova, Wastewater Protection and Treatment: Textbook, Almaty University of Power Engineering and Telecommunications, Almaty, 2016, p. 115.

[6] T.S. Zhandauletova, F.R. Dauletbakov, Z.K. Orzhanova, K.G. Mustafin, N.S. Bekmuratova, Research of Ways to Improve Water Quality, International Scientific and Practical Conference World Science, Vol. 1, 2016, pp. 20–22

[7] F.R. Zhandauletova, Integrated management of water resources in Kazakhstan, Almaty Univ. Power Eng. Telecommun. J., 2 (2013) 42–49.

[8] A.Y. Yefimov, I.M. Tavartkiladze, L.I. Tkachenko, Textile facility wastewater treatment, Kyiv Tekhnika J. [Engineering], 232 (1985) (in Russian).

[9] I.F. Judkins Jr., Tektiel waster, Water Pollut. Control Federation, 54 (1982) 702–704.

[10] Urbiniy, Trattamento di Scarichi di tentoria canterre di diatomec attivate, Inqan bient. Inquinedepur, 9 (1980) 506–507.

[11] G. Mckay, Waster Color Removal from Textile Effluents, American Dyestuff Reporter, vol. 68, 1979, pp. 29–34.

[12] A.I. Zhukov, L.G. Demidov, I.L. Mongait, I.D. Rodziller, Industrial Facility Sewers, Moscow, 2007.

[13] Dyeing Process Wastewater Treatment, Takano Kiiti, Japan Patent 55-3984.

[14] S.M. Doshi, J.R. Filial, Water pollution in textile industry, Tse Indian Text. J., 92 (1982) pp. 75–83.

[15] S.E. Hrudey, Water reclamation and reuse, J. Water Pollut. Control Federation, 53 (1981) 751–767.

[16] Wastewater Treatment Plant, Zhandauletova Farida Rustembekovna, Republic of Kazakhstan, Provisional Patent 15151.

[17] U. Baumgarte, Developments in vat dyes and in their application 1974–1986, Color. Technol., 17 (1987) 29–38.

[18] T.V. Gusev, Y.P. Molchanova, E.A. Zaika, V.N. Vinichenko, E.M. Averochkin, Hydrochemical indicators of the state of environment, Socio-Ecological Union, Moscow, 2000 (in Russian).

[19] A.K. Chapagain, A.Y. Hoekstra, The global component of freshwater demand and supply: an assessment of virtual water flows between nations as a result of trade in agricultural and industrial products, Water Int., 33 (2008) 19–32.

[20] UNEP, Water Footprint and Corporate Water Accounting for Resource Efficiency, United Nations Environment Programme, 2011. Available at: http://www.unep.fr/shared/publications/pdf/DTIx1411xPA-WaterFootprint.pdf

[21] A.Y. Hoekstra, A.K. Chapagain, M.M. Aldaya, M.M. Mekonnen, The Water Footprint Assessment Manual: Setting the Global Standard, Earthscan Publishing, London, UK, 2011.