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RESEARCH ARTICLE

ANALYSIS OF WASTEWATER TREATMENT AND RECYCLING IN TEXTILE ENTERPRISES

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ABSTRACT

Wastewater treatment of textile enterprises is a critical issue. The article reviews wastewater treatment methods of textile enterprises ensuring the achievement of such indicators of pollutants' content that later allow the reuse of wastewater in the system of recycling water supply or discharge into the municipal sewerage system. In the research and employment of an experimental plant, the physical and chemical characteristics have been revealed, as the quality standards of water and other. As studies have shown, reagent pressure flotation with the use of mineral coagulants in combination with thin-layer sedimentation and ozonation can effectively reduce the number of such pollutants as synthetic surfactants, suspended solids, significantly reduce the color of drains. Thus, the proposed treatment methods make it possible to achieve the required wastewater quality.

KEYWORDS

Colorants; Reactant air floatation; Coagulants; Thin-layer sedimentation; Ozonation; Ion exchange.

1. INTRODUCTION

The environmental pollution issue, and especially water pollution, is one of the most relevant today. The development of industry, as well as the use of various chemical products in agricultural production, has led to the emergence of significant volume and extremely diverse composition of wastewater. The implementation of water reuse and recycling systems is a key solution for reducing wastewater volumes. It is especially important for enterprises in the textile industry since the application of many dyes, synthetic surfactants and textile auxiliaries in the technological process makes the composition of wastewater of such enterprises specific and complicates the problem of its treatment (Kulikova and Kovrov, 2020; Kulikova, 2021). The issue of wastewater treatment and processing at textile enterprises is gaining relevance. There are good reasons for responding to a potential problem.

- Environmental pollution. The textile industry is one of the most polluting industries. Textile production often uses large amounts of water and chemicals that end up in wastewater. These substances can pollute water bodies and the environment.
- Water conservation. Effective wastewater treatment and recycling can help textile businesses reduce water consumption, as treated water can be reused in production processes.
- Compliance with legislation. Many countries have implemented strict water pollution regulations, and textile companies must comply with these requirements. Wastewater treatment and recycling can help companies avoid fines and sanctions.
- Social responsibility. Companies involved in wastewater treatment and processing demonstrate their responsibility to society and the environment. This can improve the company's reputation and increase its attractiveness to consumers and investors.

Therefore, wastewater treatment and processing at textile enterprises are of great importance for the preservation of the environment, the rational use of water resources, and the maintenance of a positive image of the enterprise. Taking into account the above factors, the relevance of wastewater treatment and processing at textile enterprises is very high. The implementation of effective wastewater treatment and treatment systems contributes to the sustainable development of the textile industry and the preservation of the environment.

As of today, the list of the most widespread dyes includes about 2.5 thousand substances. At the same time, the maximum permissible concentrations (MPC) of dyes in water are rather low (0.1-0.0025 mg/l), and due to high molecular weight and complex structure, they are practically not subject to biological degradation (Queiroz et al., 2019; Pala, and Tokat, 2002; Yaseen and Scholz, 2019). Without appropriate treatment, dyes contained in wastewater can remain unchanged in the environment for quite a long time (Pasichnyk, 2022; Koval et al., 2019). Separately, it should be noted that pigments that are lost with wastewater are a valuable resource for enterprises.

The nomenclature of wastewater pollutants depends on the specific dyeing process and the selected dyeing solution. Moreover, textile wastewater may contain some metals, such as iron, aluminum, and copper, as well as organic compounds such as kerosene or petroleum products

(Mostafa, 2015). In addition to the pollution problem, the textile industry is characterized by significant water consumption in some enterprises, the volume of daily consumption can reach 3000 cubic meters. The selection of a particular technological solution for wastewater treatment depends on the requirements for the quality of the treated wastewater and the cost of implementation.

Literature analysis has shown that the most promising method of deep wastewater treatment is to complement the physical and chemical methods with biological treatment, which allows the achievement of the specified parameters of wastewater. Physico-chemical methods of treatment include several different methods: coagulation, flocculation, sorption, ion exchange, and extraction (Liang et al., 2014; Solodovnik and Yakymenko, 2021; Inaba et al., 2022). There are developments where for the treatment of wastewater from textile production acidic TPP (Thermal Power Plant) waste gases are used, and the fly ash contained in them – as an adsorbent, as shown in his work "Absorption method for the neutralization of sulfur dioxide" by S.I. (Kuznetsov et al., 2020).

The disadvantages of this technology include the fact that only flue gases from coal fired TPP can be used for wastewater treatment, which significantly reduces the possibility of using this method. The method of galvanocoagulation is one of the most promising at present, but when using it to intensify the process it is necessary to connect ultrasonic influence, which leads to higher cost and complexity of the installation. Analysis of the relevant technology is given in the paper by K. Maheshwari et al. "Ultrasonic treatment of textile dye effluent utilizing microwave-assisted activated carbon" (2020). Sorption and ion-exchange methods of purification also showed high efficiency, the disadvantage of this method is the fact that usually in the third cycle of water rotation there is an increase in the concentration of mineral compounds in the working solution, removal of which is not provided by this method, which reduces the degree of dye fixation on the fabric (Kochubei et al. 2023). This problem has been highlighted in devoted to the problems of implementation of water reuse in technological cycles of textile enterprises (Wang et al., 2020).

Moreover, recently there have been developments in the application of biological methods in wastewater treatment systems of textile production. Such methods are devoted to the work of where the authors show the prospects of these solutions while drawing attention to the fact that to date, most of the developments are applicable only in laboratory conditions (Azanaw et al., 2022).

As such, currently, the most relevant is the use of local treatment facilities directly after the technological area of textile dyeing and washing (Dzigora and Stolyarenko, 2020). This method of cleaning allows the most effective treatment of wastewater for reuse in the technological process. The purpose of this study is to develop a technology for multi-stage wastewater treatment of dyeing and textile plants to bring the quality of wastewater to the indicators that allow it to be used in the circulating water supply system and to find technological solutions for use in the textile industry to reduce the consumption of clean water and reduce pollution by implementing the system water recirculation. The development of effective wastewater treatment methods will ensure the removal of pollutants, including dyes, chemicals, pesticides, heavy metals and other harmful substances. And studying the impact on the environment will make it possible to develop strategies to reduce this impact.

2. Materials And Methods

2.1 Study Area

The development of wastewater treatment technology for textile enterprises was carried out on an experimental plant, installed in the sewage pumping station of the dyeing workshop of Kustanai worsted wool and cloth factory. Dyeing plant wastewater contains various pollutants, such as dyes, chemical reagents, oils, and other substances that can be harmful to the environment and human health. Various methods, such as physical and chemical methods, biological methods and their combination, can be used to clean the wastewater of the dyeing shop of the Kustanai Worsted and Cloth Mill. For example, flotation, filtration, coagulation, and other methods can be used to remove pollutants from wastewater. At the same time, it is necessary to take into account the specifics of wastewater pollution of the dyeing shop, which may differ from other industries, and use special methods and reagents to remove specific pollutants. The development of technology for the treatment of waste water of textile enterprises was carried out at the experimental plant installed in the sewage pumping station of the dyeing shop of the Kustanai Worsted and Cloth Plant. The experimental facility allowed conducting experiments on the purification of wastewater from textile production using various methods and reagents.

2.2 Stages Of Analysis

Thus, the unit was a flow-through, its capacity was 1 cubic meter per hour (24 cubic meters per day). As a result of the water balance analysis, and instrumental and laboratory studies of wastewater composition, it was determined to use a separate wastewater treatment scheme. This was caused by a significant difference in the chemical composition of washing water from the finishing plant and concentrated wastewater from the dyeing shop. For wastewater from dyeing production, the following technological scheme of treatment is proposed: averaging, pressure flotation, thin-layer sedimentation, and filtration. For wastewater from the dyeing workshop: averaging, reagent pressure flotation, thin-layer sedimentation, filtration, and adsorption (ozonation and ion exchange).

Due to the uneven volume and significant fluctuations of pollutants content in wastewater before installation of the local processing plant the wastewater is averaged in terms of quantity and chemical composition. The averaging tank is designed to hold the wastewater for 6 to 8 hours, which allows it to achieve a homogeneous composition of wastewater before conveying directly to the local processing plant. The overflow and emptying pipelines, as well as the perforated pipelines for wastewater treatment with compressed air (barbotage), are connected to the tank-intermediate tank. After the tank-intermediate wastewater was sent to the pressure tank, where for 3-4 minutes the treatment with compressed air took place in the amount of 3-5% of the volume of purified water, the excess pressure of compressed air was from 0.2 to 0.5 MPa, to control the level of excess pressure in the pressure tank was mounted pressure gauge. Air-saturated effluents were directed to a flotation tank with a foam collector (size of flotation tank 60x70x150 cm), and coagulants were also introduced there through a floating dispenser.

Aluminum compounds, namely aluminum sulfate in doses from 100 to 200 mg/l in recalculation on aluminum oxide were used as coagulants. The next stage was the sedimentation of the treated water in a thin layer settling tank with a slope angle of 430 mm and a distance between them of 150 mm. Grain filters with keramzite coarseness 08-3.0 mm were used as filters for the final treatment of wastewater from suspended solids.

Special attention in the research was devoted to the analysis of the correlation between the cleaning efficiency and the degree of initial saturation of the treated water with air, while the pressure in the pressure tank was maintained at the level of 0.2-0.5 MPa. The water-air mixture was directed to the flotation tank after staying in the pressure tank for 3 to 5 minutes through a needle valve to reduce the pressure. Studies of wastewater processing plants were carried out using direct flow pressure flotation, for concentrated effluents – pressure flotation with fifty percent recirculation of the total flow rate. For deep preprocessing of wastewater from dyeing and textile production, ozonation technology was used (ozone concentration 10-20 mg/l in contact with wastewater from 5 to 8 minutes).

3. Results

3.1 Wastewater treatment methods for different levels of pollution

The proposed method of wastewater processing of the Kustanai worsted-fiber mill is a combination of well-proven technologies, which resulted in a sufficient level of purification for such pollutants as synthetic surfactants, suspended solids, chemical oxygen demand (COD), as well as significantly reduce the color of wastewater. At the same time, a separate treatment scheme depending on the level of contamination was proposed for the most rational use of resources. Scheme 1 shows the main technological stages of treatment for the less polluted wastewater – from the finishing plant, Scheme 2 shows the technological solutions for wastewater from the dyeing plant, which contains pollutants in much higher concentrations (Figure 1).

Note: Scheme I – treatment of rinsing wastewater, Scheme II – treatment of concentrated wastewater,1 – fiber catchers, 2 – averaging tanks, 3 – pressure flotators, 4 – thin-layer sedimentation tank, 5 – grit filter, 6 – ozonation (adsorption filter), 7 – storage tank.A practical implementation of the above-mentioned diagrams was the pilot plant shown in Figure 2.

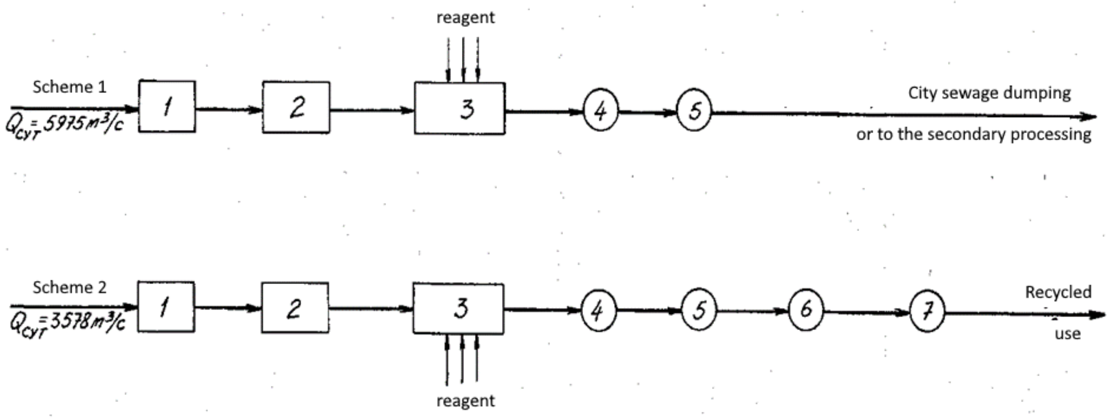

Figure 1: The separated wastewater treatment system for dyeing and textile production of Kustanai worsted wool and cloth factory

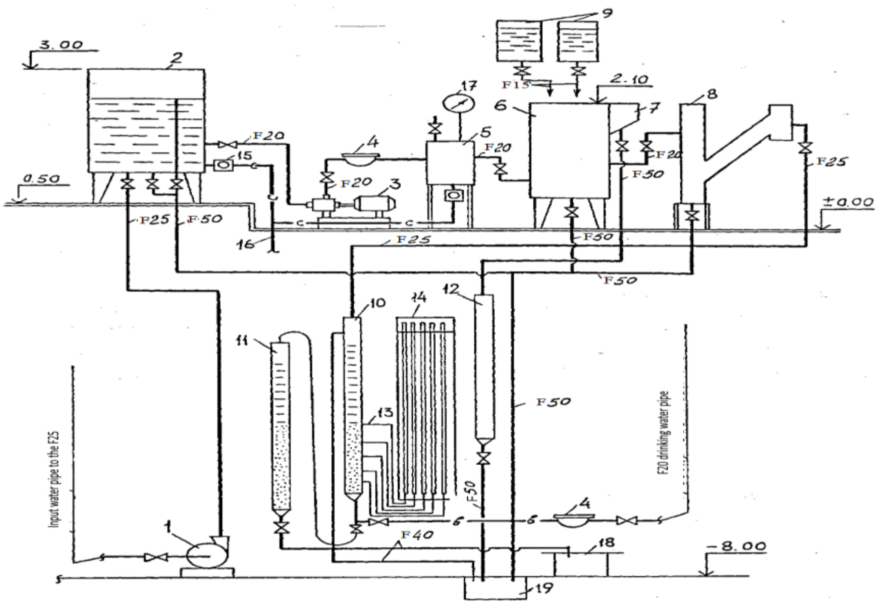

Figure 2: An experimental processing system for dyeing and textile production of Kustanai worsted wool and cloth factory.

Note: 1 – console pump, 2 – averaging tank, 3 – gear pump, 4 – water meter, 5 – pressure tank, 6 – flotation tank, 7 – foam collector, 8 – thin-layer settling tank, 9 – tanks for reagents, 10 – grit filter, 11 – ion-exchange filter, 12 – sludge thickener, 13 – sampler, 14 – piezometers, 15 – needle valve, 16 – compressed air piping, 17 – manometer, 18 – purified water tank, 19 – pit, F15, F20, F25, F40, F50 – pipe diameters.

3.2 Intensifying Wastewater Treatment: The Use of Reagent Pressure Flotation and Aluminum-based Coagulants

The purpose of the research carried out on the experimental unit was to identify the patterns occurring during supersaturation of the treated water with air and the effect of this process on the degree of purification from such substances as synthetic surfactants and dyes. The main method used in this study was the method of reagent pressure flotation. Primarily, the method involves the pre-saturation of wastewater with air at excess pressure in the pressure tank. Then the water-air mixture is throttled in the flotator with the active release of air bubbles, which create an increased surface of interphase contact (usually the size of bubbles is 15-30 microns), thus wastewater is treated from finely dispersed pollutants. However, to intensify the process different reagents are usually used, in this case, coagulants based on aluminum sulfate were used. This coagulant was chosen because it is one of the most common, which is due to its low cost and ease of use. In particular, it is easily soluble and does not require special preparatory vessels, which simplifies the technological scheme of purification. For wastewater (with a low concentration of pollutants) during the study, the experimental data on the effectiveness of purification ranged from 35 to 65% for synthetic surfactants, from 28 to 40% for COD, from 40 to 60% for suspended solids, a decrease in coloration from 65 to 75%. At the same time, wastewater was in the flotation tank and subjected to flotation from 25 to 30 minutes.

To study the process of concentrated wastewater processing (with a high content of pollutants) several experiments with different concentrations of coagulant added to the flotator were carried out. As such, the best results were achieved at concentrations of aluminum sulfate in terms of aluminum oxide from 100 to 200 mg/l. At the same time, the degree of purification of concentrated wastewater ranged from 42 to 68%, suspended solids – up to 70%, COD – from 30 to 40%, and dyes – from 45 to 70%. The duration of pressure flotation ranged from 30 to 40 minutes. Based on the obtained data the dependence of cleaning efficiency on air pressure at supersaturation was obtained for two pollutants: synthetic surfactants and colorant intensity. Thus, for wastewater at a flow rate of coagulant based on aluminum salts (in terms of aluminum oxide) 30 mg/l, the greatest efficiency was achieved at an air pressure in the pressure tank in the range of 0.25-0.35 MPa and was at this 72% for the intensity of color and 64% for synthetic surfactants. Construction of a similar dependence for the process of concentrated wastewater treatment has revealed that the most effective is the use of aluminum salt-based coagulant in terms of aluminum oxide dosage of 120 mg/l. The most effective process of reducing the concentration of synthetic surfactants and wastewater discoloration occurs at an air pressure in the pressure tank of 0.3-0.4 MPa and was 82% for the color reduction and 70% for synthetic surfactants. The absolute concentrations of synthetic surfactants in the dyeing and finishing wastewater before treatment were 65 mg/L and after treatment 23 mg/L.

It is worth noting that for wastewater processing the direct-flow pressure flotation method was applied, and for concentrated wastewater from the dyeing shop to reduce the size of the experimental plant the recirculation system was used with the recirculation flow being 50% of the total wastewater flow rate. It is worth noting that the method of direct flow pressure flotation (Dissolved Air Flotation, DAF) is an effective wastewater treatment technology that is used to separate pollutants from water by introducing air bubbles. This method is widely used for wastewater treatment in various industries, including textile, food, oil and gas, and others.

- The principle of operation of DAF is as follows: Saturation of water with air: Water is saturated with air under pressure before entering the flotation tank. This can be done using a special pump that injects air into the wastewater stream.
- Pressure Release: When the air-saturated water enters the flotation tank, the pressure is reduced. This leads to the formation of microscopic air bubbles that appear in the water.
- Contaminant Separation: Air bubbles repel solid particles and other pollutants in wastewater, forming a film that subsequently adheres to the air bubbles. Pollutants that stick to the bubbles float to the surface of the water.
- Removal of suspended pollutants: Floating pollutants are collected and removed from the surface of the water using a skimmer or other surface cleaning device.

As for the recirculation system, it is an effective way to reduce the amount of water that needs to be used in the paint shop for wastewater treatment. In this case, the system is used for concentrated wastewater, which is then subjected to research. With a recycling rate of 50%, half of the wastewater is returned to the dyeing process, thereby reducing the amount of water required for wastewater treatment. It can also reduce water and related energy costs. The experimental setup used for the analysis of concentrated wastewater can be reduced in size through the use of a recirculation system, which reduces the total volume of wastewater to be treated. Thus, the use of a recirculation system can have many advantages, including reducing the amount of water used and reducing the size of the experimental setup.

It should be emphasized that the purification efficiency for both substances reached a maximum at the same values of excess air pressure in the pressure tank. It should also be added that the decision to use thin-layer sedimentation tanks reduced the sedimentation time to 15-20 minutes. In addition, thin-layer sumps are much more compact compared to other types of sumps, their dimensions are on average 3-5 times smaller than similar samples of other types and facilitate their installation in various enclosed spaces (Zhandauletova et al., 2018a; Zhandauletova et al., 2018b).

The method of reagent pressure flotation is also effective for the removal of such pollutants as suspended solids, biological oxygen demand (BOD), COD, dry residue, and chromium, as well as the normalization of acidity from wastewater. Particularly, according to the results of experiments on wastewater treatment of dyeing and textile production, the following data on the effectiveness and yield concentrations of the above substances were obtained. For example, the concentration of suspended solids in wastewater before treatment was 220 mg/l, after treatment, this figure decreased to 88 mg/l, which is 60% of the treatment efficiency. A similar situation is observed on the BOD point: if at the inlet of the pressure flotator the concentration of BOD-poly was 340 mgO_2/l, then after the passage of the cleaning process the concentration of this pollutant at the outlet of the installation was 170 mgO_2/l, which corresponds to 50% efficiency. The COD during the cleaning process was reduced from 700 mg/L at the inlet of the unit to 427 mg/L at the outlet, i.e., the COD cleaning efficiency was 39%.

The dry residue in the wastewater before entering the pressure flotator was 1100 mg/L, while after undergoing reagent pressure flotation, this figure decreased to 750 mg/L. Thus, the cleaning efficiency in terms of dry residue was 39%. Chromium, which is one of the characteristic pollutants of textile production wastewater, as it is a part of many dyes, was also effectively removed from the wastewater according to the study results: the initial concentration of this pollutant was 0.45 mg/l. At the outlet of the pressure flotator, the concentration of chromium compounds was 0.1 mg/l, i. e. treatment efficiency of chromium compounds was 77%. Index, characterizing the content of dyes in wastewater – the dilution color intensity (dilution rate of colored wastewater to a colorless condition) – in wastewater before the treatment unit is 1:200, at the same time after treatment this index was 1:50, thus the effectiveness of cleaning on color intensity was 71%. Separately it should be noted that the process of reagent pressure flotation leads to a slight decrease in the indicator of water acidity (pH), for example, according to the results of the experiment it was found that after the pressure flotation pH decreased from 7.6 to 6.0 units.

3.3 Optimizing Textile Wastewater Treatment: Importance of Air Pressure and Post-Treatment Methods

According to the results of the study, it was found that it is the air pressure in the pressure tank that has the greatest importance for the efficiency of purification. Particularly, the optimal air dissolution pressure was determined in the range of 0.25 to 0.4 MPa. If the saturation pressure was from 0.3 to 0.4 MPa, gas bubbles release was observed in the time interval from 45 to 60 minutes, at that, some of the air bubbles were so finely dispersed that additional time was required to separate them from water. Ozonation and wastewater ion exchange were selected as methods of deep preprocessing. Ozone is an oxidizing agent with a high oxidizing potential, can be easily obtained locally from air oxygen, and is safer to use than chlorine. Separately, it should be noted that ozone can act as a catalyst for oxidative reactions involving oxygen atoms in the ozone-air mixture. Such a complex effect of ozonation allows oxidation of various inorganic and organic compounds, especially such hard-to-oxidize as synthetic surfactants, which ultimately leads to a reduction of the nomenclature of pollutants in wastewater and reduces their concentrations. In addition, ozonation does not change the salt composition of wastewater, and the products of the interaction of ozone with wastewater do not lead to secondary contamination. Ion exchange is a common method of wastewater treatment from non-ferrous and heavy metal ions, which are part of many dyes used in the textile industry.

It should be noted that the use of ion exchange as a post-treatment method is the most appropriate, since one of the main characteristics of this method is the exchange capacity of ion exchangers, which is a finite value, and at high concentrations of pollutants there is a possibility of rapid saturation of ion exchange components, which leads to reduced treatment efficiency, and hence the need for their regeneration or replacement. Ion exchange is a process used to remove ions from water and other solutions by replacing them with ions from an ion exchanger. This process can be used as a method of further purification of pollutants from wastewater. In the process of ion exchange, an ion exchanger with a certain type of ions is replaced by ions from wastewater. This process is used to remove ions that cause water pollution, such as heavy metal salts, oil, phosphates and other chemical compounds. Ion exchange can be used in various types of water treatment systems, including stationary and portable systems. It can also be used as an additional method of water treatment after other treatment methods such as filtration, sedimentation and pressure flotation. In general, ion exchange is an effective method of post-purification of pollutants from wastewater, and can be used in combination with other water treatment methods to achieve more effective removal of pollutants from aquatic environments (Yang et al., 2021). In the case of the application of this method at the final stage, when the level of contamination is already low enough, the risk of rapid saturation of ion-exchange components is not high, which allows for the achievement of optimal results and significantly increases the service life of ion exchangers. As a result of experiments, the optimal dose of ozone was established that ranges from 10 to 20 mg/l, while the time of contact of the mixture of ozone and air with wastewater should not exceed 5-8 minutes. As a result of applied methods of dyeing-finishing industry wastewater after treatment, the following results have been achieved: the concentration of suspended solids at the exit of the experimental plant was within the range from 1 to 2 mg/l, the concentration of synthetic surfactants was in the range from 3 to 5 mg/l, the dye content in treated wastewater did not exceed 1 mg/l, the concentration of dry residue was from 520 to 630 mg/l, while water acidity was 6-7 units. Thus, the overall efficiency of the set of methods suggested by the authors of the study, taking into account post-treatment is for suspended solids – 99%, for synthetic surfactants – 92%, for dry residue – 43%. It gives the right to assert that the developed technology corresponds to the purposes in view.

4. Discussion

The reagent flotation method for treating wastewater from various pollutants is widely known and widely used in many industries. The flotation process consists of the ability of gas (air) bubbles injected into the wastewater to capture pollutants (dispersed phase) and then rise together with them to the surface of the treated water. The effectiveness of the interaction of air bubbles with the dispersed phase directly depends on the adhesive-surface properties of the latter. The efficiency of the reagent flotation method can be 90%. Flocculants and coagulants can be used to intensify the processes, thus increasing the efficiency up to 95-98% (Lee et al., 2012; Kyzas and Matis, 2018). Currently, several technological solutions for the interaction of gas (air) bubbles with the dispersed phase of wastewater have been developed. Among them, the following should be highlighted: pneumatic and pneumomechanical, impeller, pressure and vacuum flotation, and electric flotation. The principle of pressure and vacuum flotation is based on the release of gas (air) bubbles under the action of differential pressure. According in her article "Method of flotation treatment of industrial wastewater" notes that despite the high dispersion of the air in this method of purification it is impossible to achieve a high degree of aeration, which respectively reduces the effectiveness of this cleaning method (Gumerova, 2015). In addition, the author points out the high-power consumption of pressure flotation.

in their article "Intensification of the processes of flotation treatment of industrial wastewater from oil products" note that increasing the efficiency of the pressure flotation method is impossible with increasing pressure in pressure tanks since the increase in the initial water supersaturation level results in the growth of average bubble size, which negatively affects the quality of treatment (Vilavskiy et al., 2016). The maximum possible working pressure of air oversaturation of the water-air mixture is 35-40 MPa. The authors note that the most effective way to increase the level of purification is the use of several stages of wastewater treatment in series, especially the methods associated with the use of multi-chamber flotators are highlighted. Other authors have also considered the problem of wastewater treatment in textile industry dyeing mills. Particularly, in the work of devoted to the study of coagulants doses for textile wastewater treatment methods based on the use of such reagents as coagulants and sorbents were considered (Amonova et al., 2019). At the same time a coagulant based on aluminum salts, namely aluminum sulfate Al2(SO4)3-18H2O, was considered and bentonite in a concentration of 6 g/l was used as a sorbent. As a result of studies, the authors obtained the optimum doses of aluminum salt-based coagulant, namely 0.75-1.0 g/l, while the efficiency of purification in terms of COD was from 38 to 65%, in terms of color intensity from 82 to 95%.

Through to comprehensive, in their research "Dissolved Air Flotation: A Review from the Perspective of System Parameters and Uses in Wastewater Treatment" consider the technology of pressure flotation, comparing it with other types of flotation units (Muñoz-Alegría et al., 2021). The authors conclude that one of the main advantages of this technology is the ability to obtain many small air bubbles, which increases the surface area of interfacial contact and thus allows the achievement of effective treatment of wastewater from fine impurities. To reduce the size of the saturator (pressure tank) the authors propose to use flow recirculation within 30% of the total treated effluent. To intensify the process, the authors propose to use synthetic flocculants based on polyaclyamide in a dosage of 2.5 g/m^3. However, the authors acknowledge that the introduction of flocculant had almost no effect on the efficiency of purification for such pollutants as synthetic surfactants (Mukandi et al., 2021; Xie et al., 2021; Xu et al., 2021). In the article, devoted to the study of the effect of reagents on the efficiency of wastewater treatment by pressure flotation, it is stated that although the pressure flotation is characterized by very small sizes of air bubbles, when using this technology, the limiting size for particles of pollutants that can be removed from wastewater is 10 microns by (Wei et al., 2015). Therefore, the authors of this work propose to use coagulants, employing of which ensure the agglomeration of small particles into larger compounds, thereby increasing the efficiency of the pressure flotation method. Additionally, the authors propose to increase the efficiency of purification by the additional introduction of flocculants, which can increase the size and density of the particles formed because of coagulation. A polyacrylamide-based reagent was chosen as a flocculant. The article devoted to the study of the role of surface nanobubbles in the flotation of small particles by (Li et al., 2022). The article examines the mechanisms of formation of surface nanobubbles and their influence on the flotation of various types of materials. The effects of factors such as the size and concentration of nanobubbles on the efficiency of flotation are investigated. Research also looks at the use of different techniques to detect and measure surface nanobubbles. The research results show that surface nanobubbles can be effective for flotation of small particles and can find applications in various fields such as metallurgy, chemical industry and wastewater treatment.

The efficiency of coagulants based on aluminum salts is shown in the articles "Water blending effects on coagulation-floculation using aluminium sulfate (alum), polyaluminium chloride (PAC), and ferric chloride (FeCL3) using multiple water sources" and "Simulation and control of dissolved air flotation and column froth flotation with simultaneous sedimentation" by (Park et al., 2016; Bürger et al., 2020). As a result of studies conducted by the authors of this article, the results were obtained, indicating that the method of pressure flotation can be used in textile production with efficiency sufficient for the use of treated wastewater in the recycling water supply system. As such, in the course of the experiments, it was established that concerning the textile production wastewater treatment the optimal pressure range in the pressure tank corresponds to the range from 0.3 to 0.4 MPa. In addition, to increase the efficiency of the pressure flotation method coagulants based on aluminum compounds in the recalculation of aluminum oxide in doses depending on the contamination of the initial wastewater were applied. At the same time, to intensify the process of treatment of particularly contaminated wastewater from the dye shop, a system with recirculation of 50% of the total flow of wastewater saturated with air was applied, which correlates with the conclusions drawn in the article by (Bürger et al., 2020; Zhang et al., 2022).

Based on the above-mentioned it is possible to conclude that the research topic is relevant and, on the one hand, supports the general trend of application of flotation units in wastewater treatment of fine impurities such as synthetic surfactants and dyes. On the other hand, the application of exactly such methods as reagent pressure flotation with the use of coagulants based on aluminum compounds in combination with filtration, ozonation, and ion exchange as a deep pre-treatment allowed, firstly, to improve wastewater treatment efficiency from such contaminants as synthetic surfactants and intensity of staining of wastewater, and secondly, to reduce consumption of coagulants such as aluminum compounds, used in the wastewater treatment plants. It should be emphasized that in the developed methodology it was proposed to use coagulants based on aluminum salts as the most common and well-proven technological process of wastewater treatment. Separately, it should be noted the use of a thin-layer sedimentation method, which not only reduces the time of sedimentation in the treated water but also due to its compact size allows installation based on the proposed technology, even in cramped conditions.

5. Conclusions

The goal of this study was to develop technological solutions for use in the textile industry to reduce the consumption of clean water and reduce pollution by implementing a water recycling system. The main pollutants, the reduction of the concentration of which was fundamental, were synthetic surfactants and the intensity of the effluent coloring. As a result, wastewater treatment technology based on the method of reagent pressure flotation was developed. This method consisted in the use of special chemical reagents that help to form bubbles of gas (air) on the surface of polluted particles, which ensures their release from water and the formation of foam. In the process of flotation, the foam takes with it impurities that rise to the surface, where they can be easily removed. It has been investigated that different types of chemical reagents are used in the process of reagent pressure flotation, such as flocculants, coagulants, surface-active substances, etc., depending on the nature of pollution in wastewater. In addition, additional technologies, such as settling tanks or filters, can be used to achieve greater cleaning efficiency. It was determined that the advantages of the reagent pressure flotation method are the high efficiency of wastewater treatment from various types of pollution, the reduction of treatment costs and the reduction of the amount of waste generated during the treatment process. In addition, this method can be used to treat wastewater of various origins and complexity, depending on the reagents used and the process conditions.

Coagulants based on aluminum salts were used to intensify the process. In the process of coagulation, pollution particles form agglomerates, which makes them heavier and ensures their detachment from the solution. Aluminum salts used as coagulants interact with electrostatically charged pollution particles in wastewater. This leads to the formation of granules that settle to the bottom, where they can be easily removed. Additional treatment methods such as flotation, filtration, or settling tanks are usually used to ensure maximum efficiency of wastewater treatment. It was determined that the advantages of using coagulants based on aluminum salts are their high efficiency for cleaning wastewater from various types of pollution, low cost and easy availability on the market. In addition, they can be successfully used to treat wastewater of various origins, including industrial and municipal wastewater.

Thus, the study revealed that the main factor influencing the quality of wastewater treatment is the air pressure in the pressure tank before entering the pressure flotator. The greatest efficiency showed the following parameters of wastewater treatment: for wastewater – the pressure in the pressure tank of 0.30-0.45 MPa, the dosage of aluminum salt-based coagulant in terms of aluminum oxide – 100-150 mg/l, flotation time of 20 to 30 minutes for concentrated wastewater: pressure in the pressure tank of 0.3-0.4 MPa, the dose of aluminum oxide-based coagulant 150-200 mg/l, flotation time of 30 to 40 minutes.

As additional methods thin-layer sedimentation and ozonation for deep purification were used. A feature of thin-layer deposition is its use to remove various contaminants, including biological and chemical contaminants. Ozonation, on the other hand, is a powerful oxidizing method that can remove even heavy contaminants. In the process of thin-layer sedimentation, wastewater passes through a thin layer of limestone, where various types of pollution are removed. Thin-layer deposition can be used as a stand-alone treatment method or as a preliminary step to other treatment methods such as ozonation. Ozonation, in turn, uses ozone to oxidize and remove contaminants from wastewater. Ozonation can also be used as a separate cleaning method or as an additional step after other cleaning methods. The advantages of using thin-layer sedimentation and ozonation for deep wastewater treatment are their high efficiency in removing various types of pollutants, including heavy and biological pollutants, as well as in reducing the content of organic and inorganic substances in wastewater. In addition, these methods can be successfully used to treat wastewater of various origins and complexity. Disadvantages of this method of cleaning are the high costs of maintaining and servicing the facilities used for the cleaning process. The developed methods showed high efficiency: for example, the dye shop wastewater treatment of high-polluted wastewater showed color intensity reduction of up to 75%; the efficiency of the suspended solids method was 73%, COD – 30 to 45%, synthetic surfactants – 40 to 68%. The following indexes were reached at wastewater treatment: color intensity reduction from 70 to 80%, suspended solids – from 50 to 70%, COD – from 30 to 45%, and synthetic surfactants – from 40 to 60%. The results obtained can become the basis for the industrial application of similar technologies and further developments. In addition, the research can help reduce the cost of reagents and energy used to carry out the treatment process, as well as ensure more efficient removal of various types of pollutants, such as organic and inorganic substances, solid particles and other substances that may be present in wastewater.

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