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IMPROVING THE ECOLOGICAL SAFETY OF POTATO CHIPS PRODUCTION BY DEVISING A METHOD FOR WASTEWATER TREATMENT AND RECYCLING

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The study deals with determining the effectiveness of mechanical and physical and chemical methods for the treatment of wastewater of potato chips enterprises. It was established that the wastewater that is formed at different stages of production differ in composition. Wastewater after washing and peeling potatoes is contaminated mainly with suspended soil substances of about 500 mg/l, which are not settled, and also has soluble organic substances with a value of COD of about 1,000 mg/l.

It was found that the use of coagulation-flocculation treatment makes it possible to get clear water suitable for reuse for washing potatoes. Coagulant – aluminum sulfate in the amount of 250 mg/l turned out to be effective to destroy the stability of the dispersed system. To intensify the sedimentation of coagulated flakes of suspended particles, non-ionogenic flocculant, which is recommended to be dosed after the introduction of coagulant in the amount of 2.5 ml/l, was selected. Analysis of clarified water indicates a decrease in the concentration of suspended particles up to 26 mg/l and a decrease in COD and BOD_5 to values of 262 mg/l and 176 mg/l, respectively.

The completed studies made it possible to propose a circuit of treatment of wastewater after washing potatoes, which consists of pre-filtering, reagent treatment, water clarification, and sediment dehydration. This circuit makes it possible to intensively clean the water to the standards of its discharge into the sewage network. However, additional disinfection of water with oxidizers, for example, ozone, was proposed for the reuse of clarified water to wash vegetables at an enterprise itself.

The use of the proposed circuit of intensive water treatment will allow increasing the environmental safety of the production of potato chips by preventing environmental contamination through reducing the volume of tap water consumption

Keywords: flocculation, coagulation, the greening of production, wastewater, environmental safety, production of potato chips, settling, centrifuging, suspended particles, physicochemical methods of treatment

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1. Introduction

Vegetable processing is one of the key branches of the food industry of any country. This branch of the economy is often the source of the formation of a large amount of highly concentrated industrial wastewater. The arrival of contaminated wastewater into urban drainage systems without prior treatment may be the cause of violation of the operating conditions of networks, pumping stations, treatment facilities, which in turn poses a threat to natural reservoirs [1].

Almost all food production is associated with the consumption of water from water supply systems, boreholes, or wells.

According to the purpose, water used for food production is divided into technological and technical. Technological water includes water that is a raw material and is part of food and beverages, as well as water that is in direct contact with food raw materials in the production process. Technical water (or water for technical purposes) includes water, which is used to ensure the technological process at all stages of production and operation of an enterprise in general. Thus, such water has no contact with raw materials, semi-finished products, and finished products, but is used for cooling semi-finished products and products, washing production facilities, etc.

Wastewater of food industry enterprises has high concentrations of various organic contaminations (fats, proteins, starch, sugar, etc.). Such wastewater is characterized by high rates of chemical oxygen demand (COD), biological oxygen demand (BOD), suspended substances, fats, and other contaminants.

Discharge of such wastewater into the city sewer without prior treatment is unacceptable. That is why wastewater of the food industry requires devising effective technological treatment circuits before discharging into the city drainage system, water bodies, or recycling in a closed cycle production.

2. Literature review and problem statement

Depending on the branch of food production (fruit and vegetable, distilleries, fish processing, meat and dairy, etc.), the content and the type of contaminants in wastewater differ in a wide range. Paper [2] analyzed the content of contaminants in wastewater of food production of various profiles and methods for wastewater treatment. It was pointed out that the main methods for wastewater treatment, which contain suspended substances, are mechanical methods. Chemical, physical and chemical, and biological methods are used to reduce the COD and BOD indicators. However, the possibility of recycling wastewater at an enterprise was not sufficiently explored. Wastewater of fruit and vegetable plants, which is not highly concentrated, can be appropriate for this purpose. The averaged indicators of wastewater after the operations of washing fruit and vegetable products are as follows [2]: t=18–20 °C, BOD_5=550–600 mg/l, COD=330–370 mg/l, total nitrogen=22–25 mg/l, phosphorus=3–7 mg/l. Contaminants in wastewater of fruit and vegetable plants after washing vegetables and fruits include soil particles, juice, vegetable and fruit waste. Even when the same raw materials are treated, wastewater from food enterprises can vary significantly. In addition, the composition of production wastewater can vary significantly depending on the season. However, this type of wastewater is promising for production recycling at the stage of washing vegetables from the soil.

In modern European countries, there is an intensive search for the most rational and highly effective methods and technologies for the treatment of highly concentrated wastewater of food industry enterprises [3]. Effective wastewater treatment and prevention of environmental pollution are the key to the environmental safety of existing industries. In addition, part of purified water can be returned to production and used in a closed cycle for technological needs, such as washing the premises, equipment, or vegetables. The secondary use of purified water reduces the need for discharge and also leads to the economy in the consumption of clean tap water, that is, it is economically feasible. However, purified wastewater can be safely disposed of or reused in production itself if it meets the relevant standards of drinking water quality. In each country, these standards regulate the requirements for organoleptic and toxicological qualities of water. For example, in Ukraine there is DSanPiN 2.2.4-171 [4], for EU countries it is necessary to comply with the requirements of EU Directive 98/83 [5], in the USA – NPDWR EPA [6] and others.

Physical and chemical or reagent methods are widely used in the practice of wastewater treatment – they are quite effective and simple. They can be used with almost unlimited volumes of wastewater. Coagulation and flocculation processes are widely used in many industries of the food industry in wastewater treatment [7]. The main purpose of coagulation and flocculation is to reduce the turbidity of wastewater by aggregating contaminants with subsequent settling or filtration. Various mineral coagulants, capable of forming amorphous or small-crystal structures that are insoluble in water are used for wastewater treatment.

Coagulation and flocculation processes facilitate the removal of suspended substances and colloids by concentrating them in the form of flakes (flocs) followed by separation in flotation and/or filtration systems [8]. These processes are basic for complete or partial adjustment of water characteristics determined by the most inert admixtures (silt, clay, colloids). However, there are objective difficulties associated with determining the method for wastewater treatment and selection of the type and number of reagents, because there is no universal method for water treatment. An option to overcome the corresponding difficulties is to conduct research with actual industrial liquids. When the composition and concentration of a contaminant in wastewater of different industries changes, it is necessary to change the type and the amount of reagents. That is why an intensive treatment method, a type and a dose of a reagent must be selected depending on the composition of a specific wastewater sample. Otherwise, the wastewater treatment effectiveness will be low, or reagents will be used inefficiently in large excess.

Coagulation and flocculation are the main pre-treatment methods used in industry worldwide. Aluminum and iron salts have been used to intensify the aggregation process for many years [9]. However, the choice of the type of coagulant that will work effectively also requires experimental selection and verification of its effectiveness. This issue is especially important when a coagulant is used in cooperation with other reagents, for example, as a flocculant.

However, it should be pointed out that aggregation during the use of various coagulants and flocculants is not a sufficiently studied process, which depends on many factors. The effectiveness of this method depends on the dosage of reagents [10], pH of the medium [11], time, speed and method of stirring [12], and other factors that can be affected during the optimization of the wastewater treatment process [13]. However, there are no clear recommendations on the choice of factors that can be used to treat wastewater after washing fruit and vegetable products, in particular in the production of potato chips. All this gives reason to assert that it is advisable to conduct a study dedicated to finding an effective method for wastewater treatment after washing vegetables.

In addition, an urgent unresolved issue is to ensure the resistance of formed aggregates to mechanical influence. It is known that flocs after formation are able to break during transportation to tanks or sludge dehydration devices. For example, studies of the resistance of flocs cells on the example of coal sludge in paper [14] showed that preservation of dimensions of formed aggregates depends on the concentration and dispersed composition of the solid phase. And for effective dehydration of sediment in a centrifuge, the residual rate of settling of flocs cells after mechanical stress should make up at least 2 mm/s.

The complex chemical composition of actual wastewater, which depends on the characteristics of a particular production, does not make it possible to immediately determine the type and amount of reagents, as well as to select the factors that will affect the water treatment process. That is why, in order to develop recommendations for the treatment of wastewater of a particular production, it is necessary to select effective treatment methods in each case. That is why additional research is needed to intensify the use of reagents and the conditions of their use, to conduct research into the rate of settling of the formed aggregates and their resistance to mechanical influence.

3. The aim and objectives of the study

The aim of this study is to intensify wastewater treatment after washing potatoes in order to increase the environmental safety of potato chips production. This is necessary to devise a substantiated wastewater treatment circuit after washing vegetable products.

To attain the set aim, the following tasks were to be solved:

– to analyze the composition of contamination of wastewater, which is formed at different stages of the technology of potato chips production;

– to study the effectiveness of wastewater treatment by mechanical and physicochemical methods;

– to develop recommendations on the technology of wastewater treatment to the norms of discharge in the sewerage system and secondary use of water for washing potatoes.

4. The study materials and methods

The object of this study was the wastewater of one of the existing production of potato chips. Wastewater of this production after washing and cutting potatoes contain contaminants that is characteristic of wastewater of vegetable products processing: soil particles, juice and vegetable residues. The study hypothesis compares the effectiveness of wastewater treatment methods after washing potatoes to improve the environmental safety of an enterprise. It was assumed that purified wastewater can be returned to the technological cycle of an enterprise at the stage of washing potatoes.

The procedure for research into wastewater purification from suspended and soluble particles included the following steps:

– sampling of wastewater at different stages of the production cycle;

– studying the composition of wastewater, which is formed at different stages of production, in terms of the contaminant content;

– choice of prospects for wastewater treatment to the norms of secondary use at an enterprise;

– selection of mechanical and physicochemical methods of wastewater treatment and comparison of their effectiveness;

– development of a technological circuit for wastewater treatment after washing vegetable products.

As a result of the examination of the technology of the wastewater sewage system at all stages of one of the enterprises of potato chips (Fig. 1), five wastewater samples were selected. The characteristics of these samples are as follows: run-off of a potato washing apparatus (Sample No. 1); combined run-off after washing and cleaning potatoes (Sample No. 2); juice run-off after cutting (Sample No. 3); a mixture of all wastewater from the industrial settling tank (Sample No. 4); blanching foam (Sample No. 5). Chemical analysis to determine the main contamination of the samples was carried out in a certified laboratory.

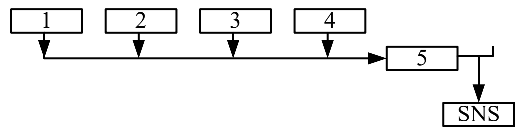


Fig. 1. Circuit of formation and sewage of wastewater of potato chips production: 1 – washing and cleaning potatoes; 2 – slicing and blanching potatoes; 3 – fats, oils that get into the sewage system because of the lack of tightness of the equipment; 4 – periodic run-off after washing the equipment; 5 – horizontal settling tank at the enterprise, SNS – sewage station

The wastewater treatment methods were selected according to the standard methods and consisted of experiments on settling, filtering, centrifugation, coagulation, and flocculation, followed by settling of wastewater samples.

The study on wastewater settling in the field of gravitational forces and with the addition of reagents (coagulants and flocculants) was carried out in standard laboratory dishes. Selection of reagents for wastewater treatment was carried out after test experiments in which three different types of polyacrylamide-based bioflocculent were used: cationic flocculant TFC-7, anionic flocculant TFA-19, and non-ionogenic flocculant TFN (technical non-ionogenic flocculant). The rate of deposition after the introduction of reagents in the field of gravitational forces and after mechanical influence on the flaked suspension was studied using the method described in [15].

5. Results of studying the methods of wastewater treatment after washing potatoes

5. 1. Results of analyzing the selected samples of liquid waste

The results of physical and chemical analysis of contamination of wastewater selected at different production stages are given in Table 1.

Samples No. 1 and No. 2 are dark turbid sludge containing suspended substances that are practically not clarified by settling. The solid phase content in Sample No. 2 is 4.5 g/l.

Sample No. 3 is a yellow turbid liquid with a high content of organic impurities and the inclusion of small pieces of potatoes that are washed off together with the run-off. It is this run-off that mainly contributes to BOD and COD, the main part of organic matter is concentrated in the suspension of this run-off (BOD=3,210 mg/l).

Sample No. 4 is a dark gray turbid liquid with flake-like sediment and a floating fraction of foam that does not settle (Fig. 2, *a*). A comparative characteristic of this sample with the results of chemical analysis showed a high fat content (187 mg/l). This is due to the fact that immediately after washing and discharging the fat-containing flow, there were quite a lot of fats on the walls of the sewage system of an enterprise and the settling tank that get into subsequent discharges, while organic substances were washed off.

Table 1

Results of analysis of samples of production wastewater

No. by order	Indicator	Measurement unit	Found in the sample
Sample No. 1. Run-off of the potato washing apparatus			
1	Suspended substances (liquid phase after settling)	mg/dm^3	553
Sample No. 2. Combined run-off after washing and cleaning potatoes			
1	Suspended substances (liquid phase after settling)	mg/dm^3	489
2	BOD$_5$	mg/dm^3	689
3	COD	mg/dm^3	964
Sample No. 3. Juice run-off after cutting			
1	Suspended substances (liquid phase after settling)	mg/dm^3	167
2	Dry residue	mg/dm^3	1,513
3	BOD$_5$	mg/dm^3	1,470
4	COD (with suspension)	mg/dm^3	3,210
Sample No. 4. The mixture of all wastewater from the industrial settling tank			
1	Suspended substances	mg/dm^3	678
2	Dry residue	mg/dm^3	1,559
3	BOD$_5$	mg/dm^3	865
4	COD	mg/dm^3	1,370
5	Ammonium nitrogen	mg/dm^3	32.5
6	Nitrates	mg/dm^3	1.3
7	Nitrites	mg/dm^3	0.46
8	Fats	mg/dm^3	187
Sample No. 5. Blanching foam			
1	Dry residue	mg/dm^3	1,580
2	BOD$_5$	mg/dm^3	395
3	COD	mg/dm^3	574

Sample No. 5 – foam after settling is a yellow turbid liquid with a high content of organic impurities and a significant inclusion of potato pieces (Fig. 2, *b*) that have fallen out of the apparatus.

a *b*

Fig. 2. General view of samples No. 4 and No. 5: *a* – flake-like sediment in sample No. 4; *b* – residues of potato slices in Sample No. 5

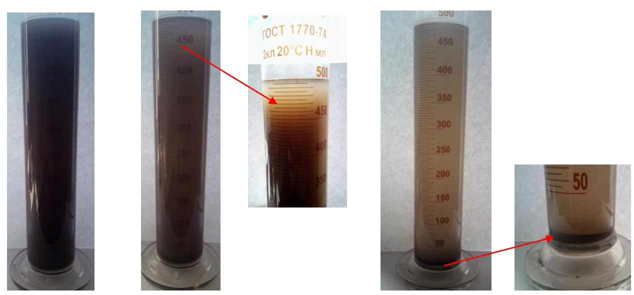
Analysis of Table 1 indicates that it is recommended to divide wastewater into the following flows requiring separate treatment: a combined run-off after washing and cleaning potatoes (Sample No. 2) and other wastewater. The combined run-off after washing and cleaning potatoes is interesting in terms of reusing in production at the stage of primary potato washing. In addition, it makes up almost 2/3 of the total volume of wastewater of the entire chip production plant, which is approximately 500–600 m^3/day.

5. 2. Studying the effectiveness of wastewater treatment methods

To study the possibility of reusing treated wastewater, we conducted the studies to assess the quality of wastewater treatment (Sample No. 2) under laboratory conditions.

As a result of analysis of the possibility of using mechanical and physicochemical methods for wastewater treatment, the following was found.

Sedimentation in the field of gravitational forces (settling) was ineffective since the solid phase is a finely dispersed phase with a hydraulic size of 0.022 mm/s (about 50 % of the particles are represented by a finely dispersed fraction that practically does not settle within 2 hours). After settling for 16 hours (Fig. 3), silt-like sediment that was poorly washed off with water and consisted of a fine fraction was observed at the bottom of the measuring cylinder.



a *b* *c*

Fig. 3. Kinetics of run-off settling after washing and cutting potatoes: *a* – after 1 hour; *b* – after 2 hours; *c* – after 16 hours

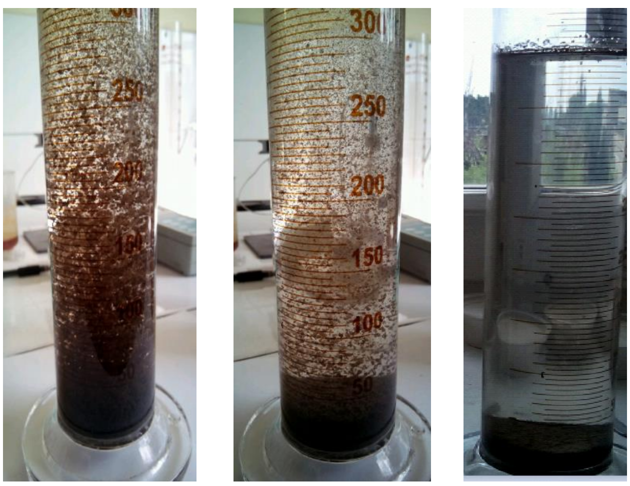
Liquid phase filtering through filter paper with the pore dimensions of 5 μm showed that only up to 500 mg/l of solid phase are caught. Filtration has a light brown shade (Fig. 4, *a*), which indicates the existence of particles of less than 5 μm (thin fractions of solid phase and colloidal suspensions). Centrifugation of the sample in the laboratory centrifuge for 30 seconds before reaching the dividing factor of 1,440 made it possible to obtain slightly turbid clarified water and sedimented suspended particles (Fig. 4, *c*).

The experiments described above suggest that the existence of finely dispersed soil and clay fractions, as well as potato juice, in wastewater create a stable dispersion system. Disruption of the dispersion system is possible by introducing polyelectrolyte (coagulant salts), which will break the stability of the system. During coagulant selection, aluminum sulfate, which in the amount of 250 mg/dm^3 ruined the stability of the system and formed small flakes of coagulated suspended particles with an average deposition rate of 0.67 mm/s, proved to be rather effective. An increase in the dosage of coagulant did not lead to a significant change in the rate of deposition of flakes. That is why in further experiments, we used exactly the same amount of coagulant and introduced a flocculant to intensify the process of deposition of flakes.

a *b* *c*

Fig. 4. Results of filtration and centrifugation of wastewater samples: *a* – filtration; *b* – caught sediment on filter paper; *c* – sediment after laboratory centrifuge

Further introduction of bioflocculant in the amount of 2.5 ml/l (0.05 % solution) made it possible to obtain clear water with a sufficient rate of deposition of flocs cells to treat water in the settling tank (Fig. 5).



a *b* *c*

Fig. 5. Aggregation of suspended particles under the influence of coagulant and flocculant: *a* – formation of aggregates after the introduction of reagents; *b* – deposition of flocs; *c* – the view of sediment and clarified liquid after settling

Comparative analysis of the samples of wastewater treated by various methods is shown in Fig. 6.

Water after settling is turbid and not suitable for discharge and reuse (Fig. 6, *a*), and the degree of catching contaminants is minimal. The concentration of suspended particles in the liquid phase after settling for 16 hours is 553 mg/l (Table 1). Filtration (Fig. 6, *b*) and centrifugation of water give a better effect (Fig. 6, *c*), the clarified water is more transparent, but has suspended particles. In addition, under industrial conditions, filtration and centrifugation of water without the use of reagents will not make it possible to obtain clarified water that was obtained under laboratory conditions.

The cleanest and most transparent water (Fig. 6, *d*) can be obtained by combining chemical strengthening of the sedimentation process with coagulation and flocculation, followed by settling. That is why this method was taken as the basis for further research and devising wastewater treatment technology for the production of potato chips.

a *b* *c* *d*

Fig. 6. Comparative analysis of the effectiveness of treatment of wastewater of chips production: *a* – settling, *b* – filtration; *c* – coagulation and flocculation with subsequent settling; *d* – centrifugation

After flocs are formed, they can be destroyed during their transportation for settling and dehydration under industrial conditions. That is why when selecting the type of flocculant, it is necessary to take into consideration not only the rate of deposition of flocs but also their resistance to destructive effects (mechanical or hydrodynamic). The results of the study of the rate of settling of flocs after the introduction of cationic, anionic, and non-ionogenic flocculant, as well as after mechanical influence, are shown in Fig. 7.

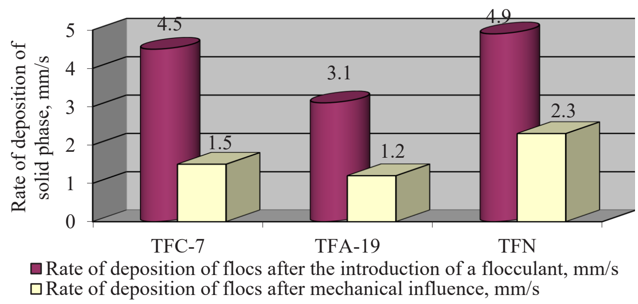


Fig. 7. Rate of deposition of solid phase after the introduction of coagulant (in the amount of 250 mg/l) and flocculants (in the amount of 250 ml/l) before and after mechanical influence by stirring for 40 s

Analysis of the test data in Fig. 6 makes it possible to recommend TFC-7 and TFN, which have a sufficiently high rate of deposition of flocs of 4.5 mm/s and 4.9 mm/s, respectively, for treatment of this production wastewater. However, the use of non-ionogenic TFN flocculant is more acceptable, because flocs retain a deposition rate after destructive effects by 1.5 times better compared to TFK-7. This is explained by the fact that the strength of hydrogen bonds when using TFN for this type of suspended particles in floccules is higher, therefore, after the floccules after destructive influence are larger. This is illustrated by microphotographs of the process of wastewater flocculation, shown in Fig. 8. That is why, for practical purposes and further research, it is possible to recommend the use of non-ionogenic flocculant TFN along with a coagulant.

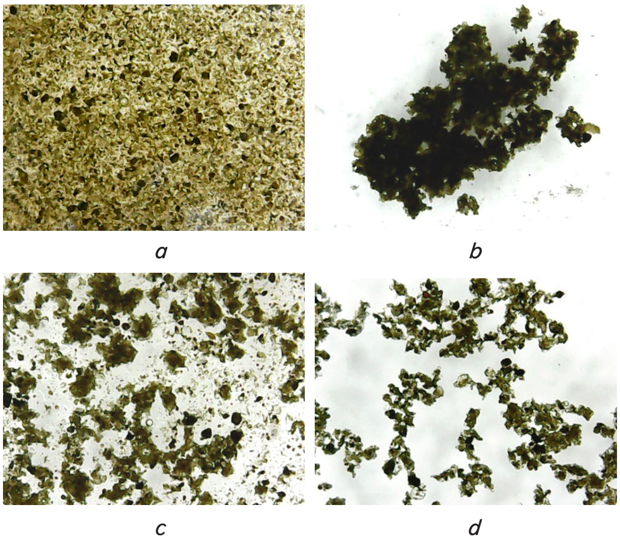


Fig. 8. Images after flocculation and destruction of flocs during mechanical influence: *a* — dispersed system in a drop of wastewater before the introduction of reagents; *b* — the view of flocs after aggregation; *c* — the view of flocs cells formed by TFN flocculant after mechanical influence; *d* — the view of flocs cells formed by TFC-7 flocculant after mechanical influence

Analysis of the results (Fig. 7, 8) makes it possible to recommend the use of non-ionogenic flocculant TFN in combination with a coagulant.

The data of comparative analysis of clarified water before treatment and after deposition of flakes with the use of coagulant and TFN flocculant are shown in Fig. 9.

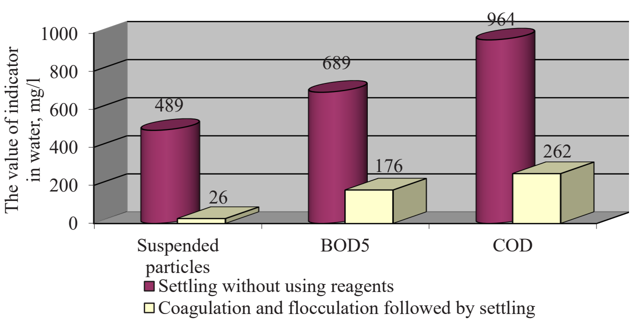


Fig. 9. Comparative analysis of the effectiveness of wastewater treatment by coagulation-flocculation method (coagulant consumption — 250 mg/l, consumption of flocculant solution — 2.5 ml/l)

Analysis of the data in Fig. 9 indicates a significant decrease in the concentration of suspended particles, BOD_5 and COD almost by 4 times. This makes it possible to conclude about the possibility of wastewater treatment for discharge into the sewage network by the proposed coagulation-flocculation method, followed by settling and dehydration of sediment.

The dependence of the change in the rate of deposition of formed aggregates before and after mechanical influence at different amount of flocculant is shown in Fig. 10.

Statistical treatment of the data in Fig. 10 made it possible to establish the following empirical equations:

$$V_1 = 0.7579 + 1.5559 \cdot q; \quad (1)$$

$$V_2 = -0.0766 + 0.8659 \cdot q, \quad (2)$$

where V_1 is the rate of deposition of flocs in a settling tank after a flocculator; V_2 is the rate of deposition of sludge after a settling tank before dehydration facilities; q is the consumption of flocculant, ml/l.

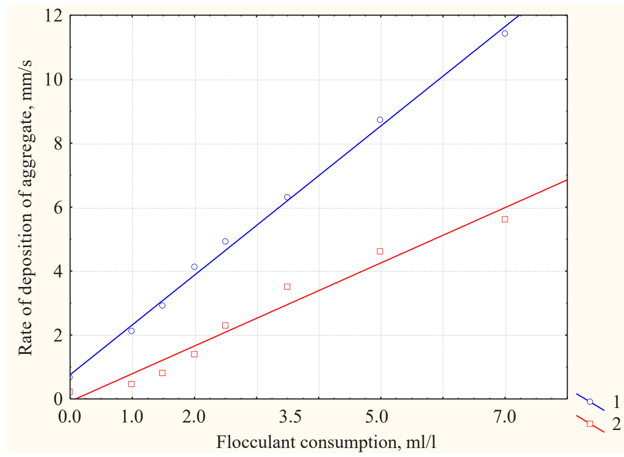


Fig. 10. Dependence of the rate of deposition of floccules after the introduction of coagulant (in the amount of 250 mg/l) and flocculant: 1 — after introduction of reagents; 2 — after mechanical influence by stirring for 40 s

The root mean square error of equations (1) and (2) in the studied interval of the values of the variables is 0.17 mm/s and 0.23 mm/s, respectively, determination factors $R^2=0.98$ and $R^2=0.97$, respectively.

These dependences can be used to predict the expected rate of deposition of flocs cells in a settling tank (1) and before dehydration facilities (2) at various consumption rates of a flocculant and constant consumption of a coagulant.

5. 3. Production scheme of treatment of chip production wastewater

As a result of the conducted study of samples, the following circuit of wastewater treatment after washing potatoes was proposed (Fig. 11).

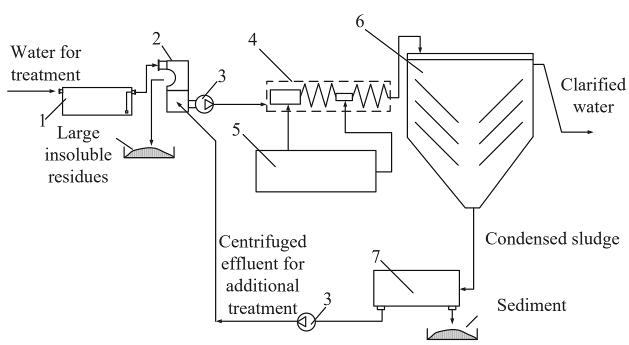


Fig. 11. Production circuit of treatment of wastewater after washing potatoes for making chips: 1 — tank-storage of wastewater; 2 — filter; 3 — pump; 4 — flocculator; 5 — station of preparation and dosage of reagents (coagulants and flocculant); 6 — thin-layer settling tank; 7 — centrifuge for dehydration of condensed sludge

Taking into consideration the existence of large plant waste, filtering should be the first stage. Wastewater from the chip production workshop is fed into the tank-storage of industrial wastewater 1 (if necessary) and then goes to filter 2, designed to separate large particles (for example, potatoes peels, and slices). After filtering 2, wastewater is fed by pump 3 for coagulation and flocculation into flocculator 4, in which there is an aggregation of suspended particles, which makes it possible to divide the heterogeneous system into clarified water and sludge. The dosage of reagents in the flocculator is carried out by the station of reagent preparation and dosage 5.

Consumption of reagents in the calculation for 1 m^3 of wastewater makes up: of coagulant (aluminum sulfate) – 250 g/m^3 and non-ionogenic bioflocculant – 7–8 g/m^3.

The flocculated sludge in a thin-layer settling tank 6 is divided into the clarified liquid phase (clean water) and a condensed product. For the sediment dehydration, a condensed product of the settling tank is fed to centrifuge 7, where it is divided into dehydrated sediment, which is a finely dispersed solid phase, and centrifuged effluent. The centrifuged effluent contains part of the suspended particles, so it returns to dilute the initial run-off for additional treatment after filter 2 and for re-treatment.

6. Discussion of results of studying the method for treatment of wastewater after washing potatoes

The creation of low-waste modern production facilities and a radical change in the technology of any enterprise requires significant economic costs. That is why greening of existing production is a promising direction for the enhancement of the environmental safety of existing enterprises. It can be implemented through a set of measures, including improving the technological processes or minimizing the amount of waste. An increase in the environmental efficiency of the processes of potato chips production can be achieved by cleaning and recycling wastewater after washing potatoes. This, in turn, will significantly reduce the intake of freshwater from natural sources. Water purified to the norms of secondary use is a valuable secondary resource for economically substantiated use in production.

The conducted studies proved the possibility of treatment of chips production wastewater to the norms of drainage. It was established that mechanical methods (settling, centrifugation, and filtering) were not effective enough. At the same time, coagulation and flocculation, followed by settling, makes it possible to get sufficiently clean, clear water that can be discharged into the sewage network. Efficiently working reagents were selected: aluminum sulfate for preliminary coagulation treatment of water and non-ionogenic TFN flocculant. These reagents destroy the resistance of the dispersed system, form contaminant aggregates and contribute to their rapid deposition. Obtained dependences of Fig. 10 and (1), (2) make it possible to select and adjust flocculant consumption, depending on the required deposition rate during water settling and dehydration.

The devised production circuit for wastewater treatment (Fig. 11) can be used to treat water after washing fruit and vegetable products in case of selection of reagents necessary for effective water clarification. The water clarified in the settling tank will correspond to the indicators shown in Fig. 9 and can be dumped in the sewage system. However, it is not enough to clean wastewater from suspended particles to the state of clear water for its re-use in the production to wash vegetable products. It is necessary to provide for the possibility of developing unwanted microbiological processes due to the biological decomposition of soluble organic substances. As a result of these processes, there is a possibility of the formation of unpleasant smell and the development of pathogenic bacteria. That is why purified water from the settling tank must be disinfected before using for production needs. One of the ways of simultaneous water disinfection and additional reduction of COD and BOD indicators is the use of ozone.

The advantage of the study is the possibility of using the given methodology (stages of research) for the selection of the type and the dose of reagents during choosing the method for the coagulation-flocculation wastewater treatment.

The limitation of the study is the fact that the above results and dependences are valid for the wastewater of a certain composition used in the experiments and production (Table 1). However, these results can be adapted to the conditions of other productions and wastewater after washing vegetables after conducting specifying tests on the selection of the method of usage, the type and the dosage of reagents.

A promising direction of the subsequent research is experimental testing of the methods for disinfection and oxidation of organic substances according to BOD and COD, which will allow the use of clarified purified wastewater in a closed cycle of an enterprise for washing potatoes. In addition, it is necessary to determine possible environmental risks and calculate the economic effect of the use of purified water for further industrial implementation of the devised technology.

7. Conclusions

1. As a result of the analysis of chips production samples, it was found that the wastewater that is formed at different stages of production differ in composition. Wastewater after washing and peeling potatoes is promising for recycling in production, but it is contaminated mainly with suspended substances of about 500 mg/l that do not get settled.

2. The effectiveness of treatment of wastewater of chips production was studied. It was found that the use of coagulation-flocculation treatment makes it possible to get clear water suitable for reusing for washing potatoes. Analysis of the results allows recommending the use of non-ionogenic TFN flocculant in combination with the coagulant (aluminum sulfate). The introduction of flocculant in the amount of 2.5 ml/l (0.05 % solution) enabled obtaining clear water with the floccules deposition rate that is sufficient for treatment in the settling tank. Analysis of clarified water indicates a decrease in the concentration of suspended particles by almost 15 times and a decrease in COD and BOD_5 by almost 4 times.

3. The completed studies made it possible to propose the circuit for treatment of wastewater after washing potatoes, which includes pre-filtering, reagent treatment, water clarification, and sediment dehydration. However, additional water disinfection by the oxidizing agent, for example, ozone, is required for the purpose of reusing clarified water to wash vegetables.

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