**Changes in the composition of microelements in wastewater during the purification process using the ion exchange method at a grain processing enterprise**

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**Abstract.** In this research, a technological proposal was developed for the reuse of wastewater generated during grain washing at a grain processing facility. The effectiveness of the obtained results was thoroughly evaluated using neutron activation analysis. The results revealed an increase in chlorine concentration in wastewater from 23,350 to 278,000 μg/l, sodium from 48,300 to 20,400 μg/l, and manganese from 15.7 to 237 μg/l, confirming the active transfer of macro and microelements into the water due to technological processes. After purification, a decrease in iron from 285 to 0.034 μg/l and manganese from 237 to 131 μg/l demonstrated the system's high efficiency in removing heavy metals. However, the high retention of chlorine (237,000 μg/l), calcium (291,000 μg/l), and bromine (3,065 μg/l) indicates the need to improve the sorption and ion exchange stages. According to the research findings, the technological scheme comprising mechanical separation, pressing, drying, and multilayer filtration significantly reduces the chemical load of water and is recommended as a scientifically-based solution for establishing water recirculation at the facility.

**INTRODUCTION**

A shortage of drinking water resources can lead to numerous problems, including mortality and health issues [1,2]. Globally, 2.2 billion people lack access to clean drinking water, with 884 million people deprived of essential water services [3]. There is a severe water shortage for urban populations worldwide, leading to destructive competition for limited water resources [4]. By 2050, the world's population is expected to reach 9 billion people. This underscores the urgency of addressing food waste and wastewater management to meet the growing needs of the population [1,2,3,4,5,6,7,8].

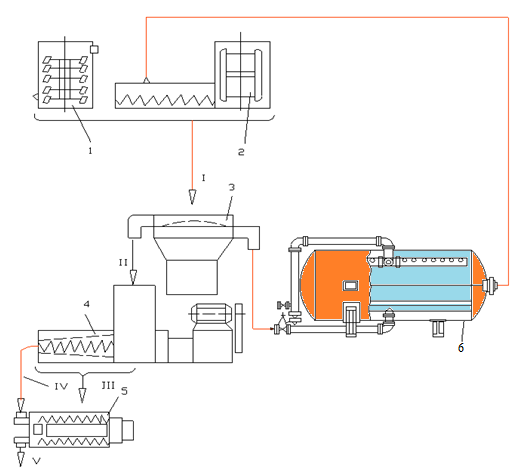
Food industry enterprises use large amounts of water, which can negatively impact the environment and require several treatment methods before wastewater discharge. To mitigate negative impacts, a comprehensive approach must be implemented, considering high process productivity, water conservation, and environmental protection to reduce water demand and wastewater generation. A detailed systematic analysis of strategies for sustainable wastewater management through the reuse and recovery of water and valuable resources was presented. The ultimate goal of sustainable operation in the food processing industry is to increase production efficiency, reduce operating costs, and eliminate environmental consequences.

Reports on industrial wastewater treatment remain limited, with data from only 22 countries accounting for 8% of the world's population. In these countries, only 38% of industrial wastewater is treated, and only 27% is safely treated [9,10].

The state reforms being implemented in our country in this field are particularly relevant in light of Presidential Decree No. PF-60 dated January 28, 2022, "On the Development Strategy of New Uzbekistan for 2022-2026." This includes measures aimed at ..."radically reforming the water resources management system and implementing a separate state program for water conservation...," which are of special importance [11,12].

**MATERIALS AND METHODS**

The system for treating wastewater generated during grain washing and moistening processes has not been fully implemented in grain processing enterprises. Scientific research in this area is also insufficient. For this purpose, research is currently being conducted on developing a technological system for processing and rational utilization of wastewater generated at grain processing enterprises in our republic. Figure 1 presents a proposed technological scheme for the treatment and processing of wastewater produced at a grain processing enterprise.



**Figure 1.** Wastewater treatment line from washing equipment:

1 - A1-BShM moisturizing treatment unit; 2 - J9-BMA washing machine; 3 - A1-BST separator; 4 - B6-BPO press; 5 - U2-BSO dryer; 6 - filter. I - wastewater; II - waste from the washing equipment; III - sewage water; IV - pressed waste; V - dry waste

In the grain cleaning section, after preliminary cleaning and black cleaning, the grain mass is treated with water. The grain is washed in either the second grain washing machine or the first hulling machine. In most cases, the second grain washer is used. Here, the grain is processed sequentially in a bath and a pressing column. The washing bath contains two adjacent troughs, each equipped with two screw conveyors - one upper and one lower. The screw conveyors rotate, powered by an electric motor through a V-belt drive and a gearbox. Grain enters the washing bath from the receiving device, where the water level should align with the axis of the upper screw conveyor. The rotating screw conveyors create a turbulent water flow, which suspends the grain and allows it to move towards the pressing column. Impurities denser than grain and with different hydrodynamic properties (such as soil clumps, stones, and metal particles) settle to the bottom of the trough. The screw conveyor moves these impurities in the opposite direction of the pressing column. The accumulated impurities, along with the water flow, are discharged into a bucket through a pipe. From the washing bath, the grain passes into the discharge chamber. As the water velocity decreases, the grain sinks into the hydraulic receiver and, under water pressure, moves to the pressing column. The pressing column consists of a lower basin-shaped frame and an upper box, connected by four legs. Plowshares are attached at a 60° angle relative to the vertical. When the whip rotor rotates, the grain moves from bottom to top in a spiral trajectory under the influence of the plowshares. During this process, the grain is subjected to multiple impacts and friction against the sieve surface. Dirt and partially the bran layer adhering to the grain separate. Together with surface moisture, they pass through the sieve holes under the action of centrifugal force and are removed from the machine. The resulting wastewater is purified from coarse mechanical impurities in separator 3 and sent to filter 6.

Wastewater is treated to separate and filter out waste materials. These operations are carried out sequentially using separator 3 and press 4. The working component of the 3rd mechanical separator is a sieve frame, which consists of a 1150 mm diameter mesh woven from stainless steel wire with hole dimensions of 0.45x0.45 mm. The frame is placed inside the sieve housing. The sieve housing moves along a horizontal plane in a reciprocating-rotating direction. (The radius of rotational oscillations is 1.4...2.6 mm). Simultaneously, angular oscillatory motion with a frequency of 1410 rpm is also applied to the housing. Wastewater from the grain washing machine is fed into the conical central part of the separator. Under the influence of rotational vibration, the waste moves towards the edge of the sieve, while the vibration process allows it to move along the sieve circumference towards the discharge pipe.

Water purified from coarse impurities is fed into filter 6. Dehydrated waste is gradually fed through the rubber sleeves of the separator into the receiving cone of the screw conveyor of press 4. Here, water is squeezed out of the washed waste. Inside the machine's pressing device housing, there is a conical sieve sleeve, inside which a variable-pitch screw conveyor rotates. Waste from the receiving device enters the pressing part of the machine and, moving with the help of the screw conveyor, is compressed between the screw conveyor and the narrowed conical space of the sieve sleeve. The separated water flows through the sieve openings onto the base and is directed to the filter. Residual sieve products and waste, compressed to the required moisture content, are discharged from the machine and sent through a gravity-flow pipe to a screw dryer for drying. Wastewater, purified from mechanical impurities, is directed to filter 6.

In filter 6, the process is carried out as follows. Water enters the filter through free flow and moves downward. This motion occurs under the influence of gravitational force. As a result, wastewater is delivered to the filter layers and moves in a slow flow. It undergoes additional mechanical cleaning through the filter mesh. In this process, large solid particles (such as grain residues and fibrous compounds) are captured in the mesh. This mechanical filtration allows water and fine particles to pass through, depending on the size of the mesh cells, while larger particles are retained. The purpose of this process is to reduce the load on subsequent delicate layers and ensure their effective operation. Next, the water passes through the activated carbon layer (adsorption). Here, organic impurities in water (starch, oil, phenols, vegetable oils) are adsorbed on the coal surface. Then it passes through the bentonite layer (ion exchange and adsorption). At this stage, inorganic ions in the water (for example, ammonium NH4+, nitrate NO3−, phosphate PO43−, and heavy metal ions) undergo ion exchange or are adsorbed by bentonite. The purified water flows through the inner and outer housing. At this stage, the water flows in layers and slowly, passing completely through the filter materials. The flow rate decreases significantly, which increases the residence time, meaning the water stays in the filter longer, enhancing the cleaning efficiency. This ensures maximum water purification from all layers. The purified water is then discharged through the drain pipe. Due to filter pressure and gravitational flow, the water flow continues. As a result, the purified water is discharged and sent back for subsequent grain moistening purposes.

To study changes in the degree of preservation of trace elements in wastewater treated by the ion exchange method, instrumental neutron activation analysis was conducted.

**RESULTS AND DISCUSSION**

In determining the microelement composition of samples using neutron activation analysis, the list of elements, factors interfering with the analysis, selection of appropriate analytical radionuclides, optimization of time parameters, and detection limits for elements were established. To increase the efficiency of the analysis, the elements were divided into three groups based on their half-lives.

Group 1. The elements Mg, Cl, I, Mn, Cu, Na, and K are characterized by the formation of short-lived radionuclides (127Mg, 56Mn, 38Cl, 128I, and others). Optimal conditions: irradiation duration - 15 s, neutron flux - 1013 n/cm2·s, cooling time - 10-15 min. The measurement time was set at 200 s for Cu, Na, K, and 50 s for Mg, Cl, Mn, and I.

Group 2. This includes elements with medium-lived nuclides such as Ca, Sm, Mo, Lu, U, Yb, Au, As, Nd, Br, La, and Cd. For these, the irradiation duration was chosen as 15 hours, cooling time as 10 days, and measurement time as 200 s.

Group 3. Elements Ce, Se, Hg, Tb, Th, Cr, Hf, Ba, Sr, Ag, Cs, Ni, Sc, Rb, Fe, Zn, Co, Ta, Eu, and Sb are determined 30 days after irradiation of samples from Group 2. The measurement duration for this group is 400-600 s.

Gamma-ray spectra were recorded using a high-precision computerized gamma-spectrometer from Canberra. Before measurements, the device was calibrated using standard gamma sources.

The results showing changes in the retention levels of microelements in treated wastewater from the waste processing line of the washing equipment presented in Figure 1 are reflected in Table 1.

Table 1 allows for comparison of the chemical composition of wastewater generated at a grain processing facility, its state before and after treatment, as well as the natural trace element composition of groundwater.

As evident from Table 1, the content of almost all trace elements in wastewater is significantly higher than in groundwater. For instance, the chlorine (Cl) content in groundwater was 23,350 μg/l, while in wastewater it was 278,000 μg/l, and after treatment it measured 237,000 μg/l. These values indicate that they result from the dissolution of salts under the influence of reagents used in grain washing, equipment cleaning, and technological processes.

**Table 1.** Amount of microelements in water, μg/L

|  |  |  |  |
| --- | --- | --- | --- |
| **Elements** | **Groundwater** | **Wastewater** | **Purified water** |
| **I** | 1206 | 9570 | 1230 |
| **Mg** | 18400 | 18900 | <100 |
| **Cl** | 23350 | 27800 | 2370000 |
| **Mn** | 15.7 | 237 | 131 |
| **Na** | 48300 | 20400 | 264700 |
| **K** | 6860 | 51500 | <100 |
| **U** | 5.1 | 0.73 | 41.8 |
| **Au** | 0.016 | 0.023 | <0.01 |
| **Br** | 45.5 | 67.6 | 3065 |
| **Ca** | 75000 | 94400 | 291000 |
| **La** | 0.22 | 1.52 | <0.1 |
| **Mo** | 8.0 | 2.4 | 1180 |
| **Lu** | 0.0077 | <0.001 | <0.001 |
| **Ce** | 0.96 | 2.4 | 3.96 |
| **Se** | 0.97 | <0.1 | 8.1 |
| **Hg** | 0.31 | 0.27 | 2.5 |
| **Cr** | 1.95 | 2.1 | 3.15 |
| **Ba** | 142 | 129 | <1.0 |
| **Ni** | <0.1 | 5.1 | 19 |
| **Sc** | 0.024 | 0.024 | <0.01 |
| **Rb** | <1.0 | 21.6 | 21.5 |
| **Zn** | 23.2 | 21.8 | 42.4 |
| **Co** | 0.11 | 0.69 | 2.3 |
| **Fe** | 109 | 285 | 0.034 |
| **Sb** | 0.59 | 0.27 | 1.42 |
| **Cs** | <0.1 | <0.1 | 0.12 |

The concentrations of calcium (Ca) and sodium (Na) are also high - this leads to increased hardness of the water used in technological processes and the formation of an alkaline environment. After purification, Ca levels range from 94,400 to 291,000 μg/l, which in some cases suggests insufficient efficiency of ion exchange or coagulation processes.

The content of heavy metals such as manganese (Mn), nickel (Ni), chromium (Cr), and zinc (Zn) in wastewater is several times higher than in groundwater. These elements primarily originate from contamination in the grain husk, corrosion of metal parts of machinery, and certain chemical agents used in technological processes. Although their concentrations decreased after treatment, in some cases (for example, Cr, Zn) they still remain at levels exceeding hygienic norms.

**CONCLUSION**

Analysis of macroelements (Na, K, Ca, Mg, Cl). The concentration of macroelements in the wastewater generated at the grain processing plant increased dramatically compared to groundwater. Specifically, the chlorine (Cl) content increased from 23,350 μg/l to 278,000 μg/l, indicating a high transfer of salts into the water and the influence of reagents used in technological processes. The levels of sodium (Na) and potassium (K) elements are also high, which is explained by the formation of compounds that create an alkaline environment. Although their quantities in the treated water decreased slightly, the elements Cl, Na, and Ca remained at high levels. This situation is attributed to the incomplete functioning of filtration and ion exchange processes or the system operating under partial load conditions.

Analysis of microelements (Fe, Mn, Zn, Cu, Cr, Ni, Se, Mo, Co, and others). The concentration of microelements in the wastewater is also considerably higher compared to groundwater. For instance, the manganese (Mn) content increased from 15.7 to 237 μg/l, and iron (Fe) from 109 to 285 μg/l. These elements are associated with mechanical impurities from grain husks, corrosion of metal equipment, and technological processing operations.

Elements such as chromium (Cr), nickel (Ni), and zinc (Zn) are important environmental indicators for industrial waste. Although their quantities decreased after treatment, some (for example, Cr - 3.15 μg/l, Zn - 42.4 μg/l) still exceeded hygienic norms. This indicates the need to improve adsorption and coagulation processes.

Analysis of rare and trace elements (Au, La, Ce, Se, Sb, Cs, etc.). These elements are found in very small quantities in water but play an important biological role in the ecosystem. Their presence in wastewater, such as increased levels of lanthanum (La), cerium (Ce), and selenium (Se), is associated with trace amounts of mineral impurities or reagents entering with grain and water. After treatment, most of these elements decreased, indicating that the filtration system has the ability to partially retain trace elements.

Post-treatment water indicators show that the system significantly reduced some metals and heavy elements, but the content of elements such as chlorine, sodium, calcium, and bromine remains high. This suggests the need to improve the ion exchange, sorption, or membrane filtration stages of the purification process.

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