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Adoption of optimal wastewater treatment system for fruit and vegetable production

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Abstract. The food industry and agro-industrial branch produce large amount of wastewater containing organic substances in high concentrations, suspended solids and cleaning agents. For small pollutant concentrations, plants dilute wastewater to standard values. However, expensive treatment is required for most of the water production process. Adoption of the most suitable wastewater treatment scheme for a fruit and vegetable enterprise is relevant because it assumes economic benefits primarily for the enterprise. The article provides an overview of existing purification systems that are suitable for cleaning specific juices of fruit and vegetable production. Using the hierarchy analysis method in this paper, an optimal wastewater treatment system of a fruit and vegetable enterprise has been selected, the main advantage of which is the possibility of returning wastewater to production.

1 Introduction

The resources of fresh water are limited. Currently, more than 780 million people do not have access to them. About 85% of global industrial and settlement wastewater is not treated, thereby polluting it [1]. The food industry and agro-industrial complex (AIC) produce large quantities of wastewater containing organic substances in high concentrations, suspended solids and cleaning agents. Wastewater treatment at agro-industrial complex enterprises producing fruits and vegetables is connected to the sewage system (indirect water discharge) inasmuch as they are often located in settlements and their wastewater is sent to municipal sewers or directly to natural water bodies [2]. Pollutant concentrations in wastewater when discharged into water bodies must be below the maximum allowable concentration, which requires pre-treatment to bring these effluents to necessary environmental parameters [3].

In general, food industry enterprises have similar wastewater treatment systems, usually including biological treatment steps. Since wastewater treatment is not a tool to increase enterprise profits, the main direction of its improvement is to reduce costs. For small pollutant concentrations, plants dilute wastewater to standard values. However, expensive treatment is required for most of the water production process [4–6].

Adoption of the most appropriate wastewater treatment scheme for a fruit and vegetable enterprise is relevant because it involves economic benefits primarily for the enterprise. In this paper, we considered several wastewater treatment technological schemes, one of which is with recycling water supply.

2 Materials and methods

The fruit and vegetable industries are characterized by the seasonal production operation, which mainly falls to the period from June to October [7, 8]. The specificity and variety of raw materials handled make it difficult to characterize the wastewater of the fruit and vegetable industry.

Most wastewater is generated at the first stage of production. Wastewater generated by washing fruits and vegetables is usually used once. At large plants, water used in the first stage is treated on screens and discharged into the sewer after washing the entire batch of fruits and vegetables, and raw water is used in its place. Wastewater from fruit and vegetable plants is characterized by high carbohydrate and mineral content and variable composition, depending on the raw material processed or the season [9].

The wastewater composition is also affected by washing and disinfection processes of processing lines. The washing process causes the transfer of various solid, colloidal impurities, dissolved substances into the wastewater, depending on the type of processed raw materials, as well as on the technological process used [6, 9]. At the same time, an undetermined number of detergents and disinfectants penetrates into the wastewater.

It is possible to distinguish several stages in which wastewater is generated:

- raw material washing;
- cleaning of raw materials;
- blanching;
- blanching of the raw material;

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- cooling;
- filling of products.

The composition and quantity of wastewater also depend on the type, quality, setting, and size of flushing and cleaning machines [10].

Wastewater generated in the production of fruit concentrates is characterized by pH in the range from 5.8 to 9.4 and COD value from 1030 to 5630 mgO_2/dm^3. At enterprises producing several product types, for example, salads, purees, marinades, the pH range of wastewater varies from 4.9 to 7.7, and COD value is from 5620 mgO_2/dm^3. These indicators depend on the production technology and processed raw materials [11].

Wastewater from fruit and vegetable production is also poor in nitrogen, and organic substances in large quantities are the main pollutant. The value of BOD_5 varies from 500 to 5000 mg O_2/dm^3, and in the period of intensive processing of raw materials, it exceeds 5000 mg O_2/dm^3 [7, 12].

Fruit and vegetable production wastewater is characterized by higher values of COD and BOD_5 and much lower concentrations of total nitrogen and total phosphorus compared to conventional domestic wastewater [13]. The ratio of COD to BOD_5 for fruit and vegetable production wastewater is 1:0.5, which indicates that wastewater is easily biodegradable [14].

In total, the enterprise has several sections:

- apple puree production section;
- section for the production of mashed vegetables or apples (depending on the season);
- apple juice production section;
- baby food production section.

Each section has its own production line, on which wastewater of various pollution is formed.

The apple puree production section works 9 months a year. At the same time, the peak of wastewater generation (production) falls on the period from September to January (5 months) – 1200 m^3/day (2 puree shops). In the remaining 4 months, the daily wastewater consumption is 720 m^3/day (2 puree shops).

Wastewater pollution in this section is represented by suspended substances, vegetable pieces, nitrates, as well as chemicals used for washing equipment.

The section for the production of vegetable and fruit puree works 9 months a year. At the same time, the peak of wastewater generation (production) falls to the period from September to January (5 months) – 1200 m^3/day. The remaining 4 months, the daily wastewater consumption is 720 m^3/day.

Wastewater pollution in this workshop is represented by suspended substances, pieces of vegetables, nitrates, as well as chemicals used for washing equipment.

The apple juice production section operates only 5 months a year (from September to January). In total, considering the organization of return cycles of used water in the production, about 500 m^3/day is discharged into the collector with a peak load per hour – 34 m^3/hour.

Wastewater pollution of this section is mainly represented by suspended substances and apple particles, which are reflected by an increase in COD and BOD indicators. In addition, wastewater pollution includes chemicals used for washing equipment.

The baby food section operates year-round with the same daily capacity of wastewater – 160 m^3/day.

Wastewater pollution of this section is mainly represented by chemicals used for washing equipment.

3 Results and discussions

3.1 Variants of wastewater treatment systems for fruit and vegetable production

Three schemes have been proposed for the wastewater treatment of a fruit and vegetable enterprise, which are shown in Figures 1, 2, 3.

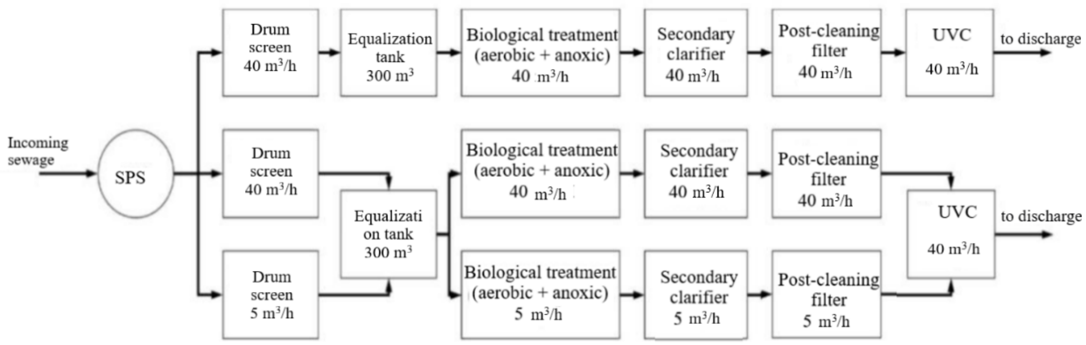

Fig. 1. Conventional wastewater treatment with wastewater discharge into a water body.

The conventional scheme of wastewater treatment is fundamental for the other two schemes. This scheme is used by most enterprises that clean wastewater by biological treatment. The main stage is the stage of biological treatment.

From the equalization tank wastewater enters the stage of biological treatment, namely the micro-mixing reactor (MMR). Active mass exchange processes take place in the micro-mixing reactor, which allows increasing the intensity of the biological treatment stage by accelerating the chemical and biological reactions. Wastewater saturated with oxygen from MMR goes to the aerobic reactor, where the nitrification process continues, and then to the anoxic bioreactor, where the denitrification process takes place. In the aerobic bioreactor and in the anoxic bioreactor, wastewater supply is organized in such a way as to avoid "blind" zones and, accordingly, to prevent violations of the purification process.

In the anoxic reactor with a reagent, farm carbohydrates are fed in order to optimize the process of biological treatment (if it is necessary, it is determined at the stage of commissioning works). From the anoxide bioreactor with the help of a recirculation pump the water-oil mixture is accordingly fed back to the MMR.

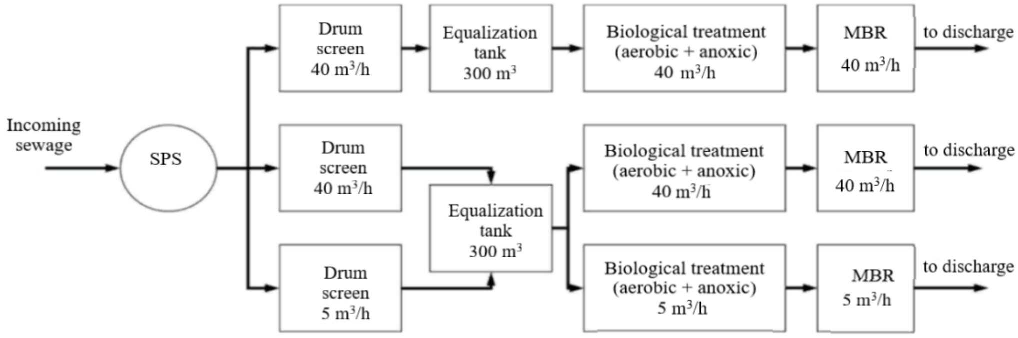

Fig. 2. Wastewater treatment with high doses of sludge with the discharge of wastewater into the river

Scheme 2 is an improved version of conventional scheme 1. This system operates at high sludge doses (12–16 g/l, which allows one to force the wastewater treatment process and thereby reduce the tanks volume. Maintenance of high sludge doses is achieved by replacing the standard sedimentation technology in secondary sedimentation tanks with Membrane Bioreactor technology. The MBR technology involves the use of submersible membrane modules, which allow ultrafiltration of the generated sludge, thus separating it from the treated water [15]. The membranes are made as laminar modules with 2 mm thick. This technology allows a significant reduction of suspended solids in the affluent, so there is no need for further filtration. In addition, the use of this unit eliminates an ultraviolet disinfection unit, as the technology provides for the removal of microorganisms and wastewater.

After wastewater treatment at the MBR unit, effluent is discharged into a water body, and it is brought up to discharged requirements.

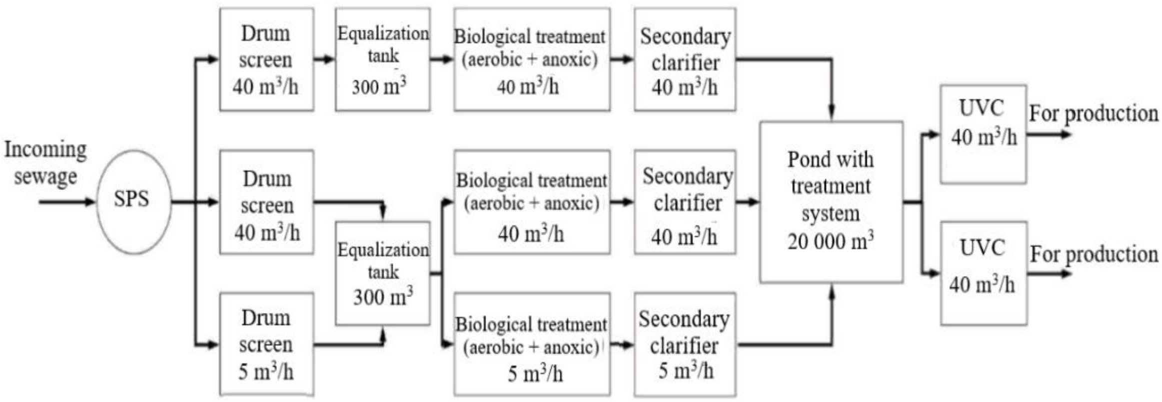

Fig. 3. Scheme 3 – wastewater treatment with recycling water supply.

The main difference between scheme 3 and the conventional treatment scheme is the presence of a pond on the enterprise site, which can be used as one of the wastewater treatment stages.

The pond will have its own treatment system in order to maintain it in an optimal environmental condition. The pond cleaning system involves the installation of a "Whalefish" device. The device "Whalefish" creates optimal conditions for the growth of aerobic bacteria in the pond. In the process of continuous operation of the device "Whalefish", the community of aerobic bacteria reaches the required balance. The biological impact of the required number of bacteria allows eliminating consequences of negative impacts on the reservoir. As a result of the process in "Whalefish" there is no pond aeration, but conditions are created for the life activity of aerobic bacteria already existing in this environment [16]. Thus, the water will have optimum indicators, which will allow using it for reuse in production as technical water (e.g. for washing fruits and vegetables in the first stages of the technological line).

To avoid contamination by pathogenic organisms in fruits and vegetables at the washing stage, an ultraviolet disinfection unit will be used after drawing water from the pond.

As an alternative to secondary sedimentation technology, membrane bioreactor technology can be used. MBR technology involves the use of submersible membrane modules, which allow the process of ultrafiltration of the resulting sludge, thereby separating it from the treated water.

3.2 Adoption of optimal wastewater treatment system for fruit and vegetable production

The hierarchy analysis method developed by T.L. Saati [17] can be used to select the most suitable wastewater treatment scheme.

The MHA algorithm includes the following stages:

- formation of a hierarchy of goals;
- definition of priorities;
- calculation of local priority vectors;
- checking of expert estimations for consistency (calculation of the consistency index);
- calculation of priorities of goals and measures for the hierarchy based on the synthesis of local priorities.

Initial data, based on which the analysis was carried out, were provided in the enterprise concept.

Formation of the goal hierarchy. Decomposition of the decision-making problem with the allocation of the main objectives, sub-objectives, and various target functions (alternatives) is performed. Elements of the same levels should be comparable to each other in terms of the possibility of prioritization (Figure 4).

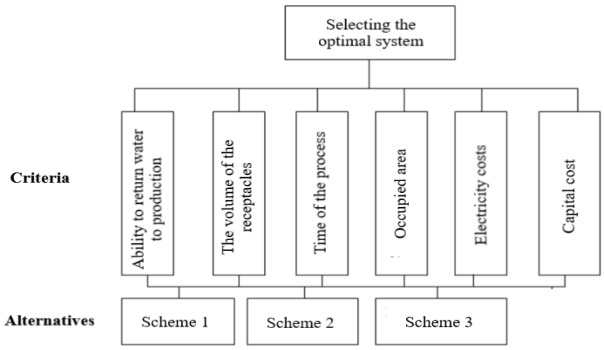

Fig. 4. Hierarchy of the cleaning system selection problem.

Prioritization. In order to prioritize the criteria, to obtain estimates for the alternatives, matrices of pairwise comparisons A = aij are constructed. The element aij of the matrix of pairwise comparisons is the result of measuring on a fundamental scale the degree of preference of the alternative Ai with respect to the alternative Aj.

Calculate local priority vectors. For each matrix, we can calculate the local priorities of the elements being compared. (Table 1).

Table 1. Evaluation of Criteria Importance.

	C.1	C.2	C.3	C.4	C.5	C.6	Product	$\sqrt[6]{}$ of the product	Local vector of priorities
C.1	1	9	5	7	4	3	3780	3.947	0.444
C.2	1/9	1	1/5	1/3	1/6	1/7	0.0002	0.237	0.027
C.3	1/5	5	1	3	1/2	1/3	0.495	0.891	0.1
C.4	1/7	3	1/3	1	1/4	1/5	0.007	0.439	0.049
C.5	1/4	6	2	4	1	1/2	6	1.348	0.152
C.6	1/3	7	3	5	2	1	69.3	2.03	0.228
Total	2.04	31.00	11.53	20.33	7.92	5.18		8.886	1

The following criteria were used in the calculation:

- C.1 – Ability to return water to production;
- C.2 – The volume of the receptacles;
- C.3 – Time of the process;
- C.4 – Occupied area;
- C.5 – Electricity costs;
- C.6 – Capital expenditures.

At this point, we can conclude that the ability to return water to production is the most important factor in choosing a wastewater treatment system, and the volume of tanks is the smallest.

Checking the boundedness of the evaluation of priorities. At this stage, the so-called consistency index (CI) of judgments for each matrix is calculated.

The value of the RC depends only on the dimensionality of the matrix of pairwise comparisons.

At this stage, it has been revealed which of the wastewater treatment schemes is most preferable for each of the criteria. The calculation results are shown in the table and are based on the value of the priority vector for each of the criteria. The most preferred wastewater treatment schemes are selected based on global priority values (Table 2).

Table 2. Global Priority Vector Calculation (GP).

	Priority Vectors						
	C.1	**C.2**	**C.3**	**C.4**	**C.5**	**C.6**	
	0.444	0.027	0.1	0.049	0.152	0.228	GP
Scheme 1	0.077	0.127	0.172	0.144	0.153	0.278	0.149
Scheme 2	0.117	**0.687**	**0.726**	**0.760**	0.070	0.058	0.204
Scheme 3	**0.806**	0.186	0.102	0.096	**0.777**	**0.663**	**0.647**
Total							1

According to calculations, scheme 1 has no significant advantages.

Scheme 2 has an advantage according to such criteria as the volume of containers, the time of the process, and the occupied area. These indicators are achieved through the use of high doses of sludge and MBR technology. However, the improvement of these criteria is not the main task in the construction of the complex. It is also worth noting that this cleaning system is characterized by high cost and significant operating costs.

Comparing the obtained values of global priorities, the ratings of all cleaning schemes were determined. The highest priority of 0.647 corresponds to scheme 3 (the wastewater treatment system of a fruit and vegetable enterprise with the return of treated wastewater to production). This scheme has several advantages. First, this is the possibility of returning treated wastewater to production. Since the waste water of fruit and vegetable production is characterized by a high organic content, it does not make sense to use expensive cleaning according to these indicators. The most profitable solution would be to return the effluents to production without additional purification of the effluents from organic matter. It is also worth noting that cleaning scheme 3 is the least expensive during the construction and operation of treatment facilities. This is due to the presence of a reservoir on the production site, in which part of the biological purification process will take place.

According to the evaluation carried out by the hierarchy analysis method, preference should be given to this water treatment system.

4 Conclusion

Wastewater of a fruit and vegetable processing plant has its own specifics. They contain a large amount of organics that depend on the season and the amount of processed crops. In order to ensure that the wastewater does not pollute the environment, it is necessary to adopt an optimal treatment process.

In the course of this work, wastewater features of fruit and vegetable enterprise, their indicators were studied, several options of wastewater treatment with subsequent discharge into water bodies (in accordance with the regulatory framework) or with reuse as technical water were considered.

The scheme of wastewater treatment with recycling water supply for washing fruits and vegetables at the first stages of the technological line was chosen for the fruit and vegetable enterprise. To optimize the wastewater treatment process in terms of speed, efficiency, and economic benefits, it is recommended to use the wastewater treatment system according to scheme 3.

References

1. B. Ki-moon, *Opening Remarks at Budapest Water Summit* (2013), Retrieved from: https://www.un.org/sg/en/content/sg/speeches/2013-10-08/opening-remarks-budapest-water-summit
2. A.I. Kurbatova, A.D. Dalidenok, K.Y. Mikhaylichenko, E.V. Savenkova, E.V. Kruglikova, A.I. Adarchenko, The impact of wastewater from Moscow Domodedovo Airport on the quality of water in surface reservoirs, Ecol. and industry of Russ. **24**, 67–71 (2020)
3. SanPiN 2.1.5.980-00, *Water disposal in populated areas, sanitary protection of water features, Hygienic requirements for the protection of surface waters*, Date of introduction 01.01.2001
4. Ministry of Natural Resources and Ecology of the Russian Federation, Retrieved from: http://www.mnr.gov.ru/regulatory/detail.php?ID=128717
5. M. Puchlik, Application of constructed wetlands for treatment of wastewater from fruit and vegetable industry, J. Ecol. Eng. **17(1)**, 131–135 (2016)
6. A. Basamykina, E. Kurkina, M. Kameristaya, V. Zelenina, Integrative principles and criteria for implementation of faecal sludge management in Russian Federation, E3S Web of Conf. **265**, 1–9 (2021)
7. M. Soroko, Treatment of wastewater from small fruit and vegetable processing plants in wetlands, Water Environ. Rural Areas **3**, 119–128 (2003)
8. S. Kierczyńska, Production of vegetables and fruit and their processing in Poland, Annals Ser. **4**, 161–167 (2008)
9. A. Nawirska, Water and sewage management in the fruit and vegetable industry, Agro Przemysł **3**, 65–67 (2007)
10. A. Nawirska, L. Szymański, *Water and Sewage Management in Food Industry Plants* (Agricult. Univ. Publ. House, Wroclaw, 2002)
11. D. Kopiec, Wastewater from the food industry – Experience from the Municipal Wastewater Treatment Plant in Blonie, Communal rev. **2**, 47–50 (2007)
12. B. Talik, B. Chudzik, Treatment of wastewater from small fruit and vegetable processing plants located in the countryside, Wiad. IMUZ **20(3)**, 199–212 (2000)
13. K. Ignatowicz, J. Smyk, Ecological solutions of sewage and heating management in the monastery in Zwierki, J. of Ecol. Eng. **40**, 7–16 (2014)
14. M. Puchlik, K. Kosińska, Characteristics of raw wastewater from the fruit and vegetable industry, J. of Ecol. Eng. **48**, 181–185 (2016)
15. A.N. Basamykina, M.I. Khorisov, Specialty of wastewater treatment by using membrane bioreactors (MBR), *Environmental Problems of the Third Millennium Proceeding*, Int. Youth Sci. Conf. (2016), Vol. 2, pp. 244–248
16. A.N. Basamykina, A.I. Kurbatova, E.V. Savenkova, E.V. Kurkina, The possibility of intensification of aerobic biochemical processes at the stage of biological wastewater treatment Study of aquatic and terrestrial ecosystems: history and modernity, *International Scientific Conference dedicated to the 150th anniversary of the Sevastopol Biological Station – the A.O. Kovalevsky Institute of Biology of the South Seas and the 45th anniversary of the NIS "Professor Vodyanitsky"* (Sevastopol, 13–18 September, 2021), 576 p.
17. T.L. Saaty, *The Analytic Hierarchy Process* (McGraw-Hill, New York, 1980)