Simulation modeling as a tool for predicting the quality of wastewater treatment in food production

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Abstract. The possibility of using simulation modeling to predict the quality of wastewater treatment in food production is considered using the example of the baking industry. Using the GPS-X 8.0 software product, the efficiency of wastewater treatment processes at local wastewater treatment plants for the production of bakery products, confectionery products and mixed-type production with the production of bakery products, small baked goods and confectionery production was studied. It is shown that the use of a systematic approach ensures the development of effective local facilities for wastewater treatment.

1 Introduction

All industrial wastewater, especially from enterprises included in the list established in the Decree of the Government of the Russian Federation, and in accordance with the amendments made to Federal Law No. 416-FZ "On Water Supply and Wastewater Disposal", must undergo mandatory treatment before being discharged into public sewer networks . These include wastewater from food production, including bakery enterprises.

Currently, the food industry is one of the most dynamically developing industries in Russia. Most food processing plants generate low-hazard waste, and a significant portion of the contaminants is contained in wastewater. The main volume of wastewater is generated during the washing of containers and equipment, as well as after cooling systems. Basically, wastewater is contaminated with residues of raw materials, semi-finished products, finished products, and detergents. Not all operating enterprises are equipped with wastewater treatment facilities; often the equipment of treatment facilities is outdated and requires modernization. Until now, production at bakery and confectionery enterprises has been considered one of the most environmentally friendly, and the technological design standards for bakery enterprises provided for the discharge of wastewater into the city sewerage system without treatment. Accordingly, treatment facilities that take into account the specific composition and formation of these waters have also not been developed, as shown by an analysis of literature data on this issue [1-2].

Wastewater from bakery and confectionery industries was once considered slightly polluted, but today has become a source of significant pollution due to the introduction of

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new ingredients and food additives into production that increase the content of dissolved organics and other pollutants in the effluent. Industrial discharges from bakeries contain a large amount of suspended solids and organic impurities, which serve as a medium for the development of many pathogenic bacteria. In addition, when discharged into a citywide sewer, some impurities can form highly toxic compounds [3].

With the development of technology, various enterprises began to produce wastewater of different compositions and volumes, which makes it difficult to develop and standardize the treatment process. Unevenness of water consumption also leads to problems, since the coefficient of unevenness of flows can vary.

To treat wastewater at bakery enterprises, traditionally only grease traps were installed, but nowadays, in order to meet the required quality standards, the use of more complex systems with physico-chemical methods and post-treatment is becoming relevant.

A good solution is to install local treatment facilities (LTF). To simplify the process of developing local treatment facilities and reduce treatment costs, it is advisable to use prediction of treatment quality using simulation modeling.

2 Materials and methods

Based on the nature of pollution, industrial wastewater from bakeries is divided into water contaminated with flour and flour impurities, water in cooling systems that has specific contaminants, as well as domestic wastewater.

The work analyzed three types of wastewater: wastewater from a bakery, confectionery shop and mixed production producing bakery products, small baked goods and confectionery products (Table 1) [4].

Table 1. Composition of wastewater from bakery industry enterprises.

Index	Indicator values			MPC
	Bakery shop	Confectionary shop	Mixed effluents	
COD, mg/dm^3	900	590-2012	9.65	500
pH	7.2	6.2-9.2	7.03	6-9
BOD, mg/dm^3	600	1060	4.4	300
Explosive, mg/dm^3	1000	184	1.22	0.25
Temperature, °C	30	30-50	20	22

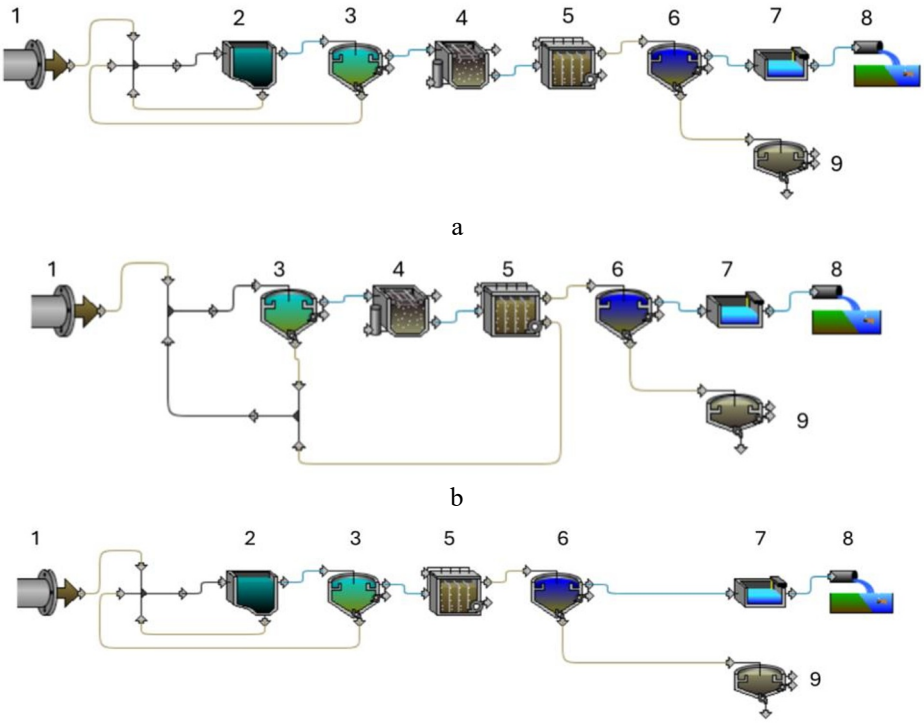
To predict the quality of wastewater treatment, the method of simulation modeling of treatment processes in the GPS-X 8.0 software product (Hydromantis, Canada) was used. This program is used to simulate the operation of treatment facilities of various types and allows you to select the most efficient structures at the development and design stages.

The GPS-X software product allows you to simulate the wastewater treatment processes of individual installations, as well as the entire complex of wastewater treatment plants (WTP) using various built-in libraries (Activated Sludge Model - ASM1, ASM2, ASM3, etc.). In addition, GPS-X can be used to estimate energy costs as part of the operating costs of wastewater treatment.

3 Results

The concentrations of suspended solids, chemical and biological oxygen demand (COD and BOD) in wastewater are significantly exceeded. According to the literature, flotation and biological treatment units are recommended for wastewater with this composition [5–9].

In bakery shops, one of the distinctive features is the use of baker's yeast, which determines the content of living microorganisms capable of growth and development under favorable conditions and when released into the natural environment. In this regard, methods based on the biological decomposition of pollutants by activated sludge microorganisms are currently used to reduce the discharge of pollutants into surface water bodies. These methods are quite effective in terms of the degree of purification achieved, although the cost of operating biological treatment facilities remains quite high. Widespread application confirms the effectiveness and promise of a number of electrophysical methods: electroflotation, electrocoagulation, electrooxidation, microwave wastewater treatment, etc. To treat wastewater from bakery production, a local scheme of treatment facilities was modeled using sedimentation, flotation/coagulation and biological treatment units (Figure1, A).



1 – input stream; 2 – sand trap; 3 – primary settling tank; 4 – flotator; 5 – biological stage of purification; 6 – secondary settling tank; 7 – ozonation; 8 – output stream; 9 – sludge compactor

Fig. 1. Modeling schemes of local treatment facilities for bakery industry enterprises: a) treatment facilities of a bakery shop; b) treatment facilities of the confectionery shop; c) treatment facilities of a bakery with mixed wastewater.

In confectionery production shops, various raw materials are processed: sugar, molasses, fruit puree, nuts, soybeans, beans, cocoa, milk, dairy products, etc. Therefore, the wastewater here has specific contaminants. Sources of education: technological processes, washing of containers, equipment, cooling systems. The main amount of wastewater in confectionery shops is formed during the washing of cookers, pipelines, receiving tanks, baths, washing of technological equipment, as well as due to condensate from boiling down the raw materials.

A characteristic feature of wastewater from confectionery enterprises is the presence in its composition of organic substances that are in a dissolved, colloidal and suspended state. Basically, these are the remains of raw materials: flour, dough washes, sugar, eggs, fats and other raw materials provided for in the recipe. Wastewater from the confectionery industry is poorly filtered, quickly sours and rots. The main organic pollutants in wastewater from confectionery shops are not toxic and are easily susceptible to biochemical oxidation in biological structures with the formation of humic and fulvic acids, which promote the transition of soluble metal salts into their chelate compounds. Surfactants and petroleum products have increased resistance to microbial decomposition (Figure 1, b).

Mixed wastewater from bakery production, including the production of bakery products, confectionery products and small baked goods, contains various pollutants: from suspended solids to microorganisms (Table 1). After studying the literature sources [10–12], it was revealed that flotation or coagulation units and settling tanks with subsequent fine treatment are used to purify these wastewaters (Figure 1, c).

Treatment facilities recommended according to the literature, taking into account devices for different wastewater compositions, were modeled in the GPS-X software product (Figure 1).

The modeling results are shown in Table 2. As indicators at the entrance to local treatment plants, the concentrations of pollutants according to Table 1 were taken as average concentration values. To increase the reliability of the modeling results, the values of indicators at the entrance to local treatment facilities were increased and decreased by 20% from the average value. Temperature, pH and wastewater flow were assumed constant.

As can be seen from Table 2, the considered treatment facilities are suitable for the corresponding types of wastewater, providing a fairly high predicted treatment effect in almost all indicators with both an increase and a decrease in concentrations at the entrance to local treatment facilities, which allows us to conclude that the proposed schemes can be recommended for further design.

However, of significant interest for further feasibility studies of the proposed facilities is the consideration of energy costs for treatment and associated operating costs (Figures 2 and 3).

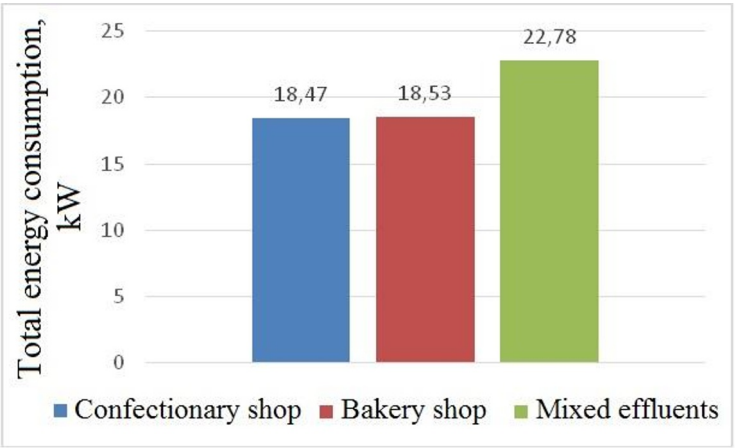


Fig. 2. Total energy consumption for wastewater treatment plants for bakery production, confectionery production and mixed baking production.

Table 2. Forecasting the efficiency of wastewater treatment at local treatment facilities.

Concentration, mg/dm³	Vzv. in-va, mg/dm³	COD, mg/dm³	General nitrogen, mg/dm³	General phosphorus, mg/dm³
Bakery production				
At the entrance of local treatment facilities				
Average value	108.2	152.4	6.4	1.4
Less than average by 20%	169.1	82.8	6.7	1.3
St. average by 20%	12.9	398.2	11.1	4.1
At the entrance of local treatment facilities				
Average value	0.0	0.7	0.6	0.2
Cleaning effect, %	100.0	99.5	90.6	85.7
Less than average by 20%	0.0	2.3	0.4	0.2
Cleaning effect, %	100.0	97.2	94.0	84.6
St. average by 20%	0.0	1.1	1.5	0.2
Cleaning effect, %	100.0	99.7	86.5	95.1
Confectionery production				
At the entrance of local treatment facilities				
Average value	138.2	155.6	3.9	4.5
Less than average by 20%	248.1	237.1	10.9	3.5
St. average by 20%	209.7	538.2	23.2	3.2
At the entrance of local treatment facilities				
Average value	0.0	1.9	0.9	0.2
Cleaning effect, %	100	98.8	76.9	95.5
Less than average by 20%	0.0	2.9	1.1	0.3
Cleaning effect, %	100	81.8	71.8	88.9
St. average by 20%	0.0	0.9	0.9	0.4
Cleaning effect, %	100.0	99.8	25.8	0.87
Mixed production: bakery and confectionery products				
At the entrance of local treatment facilities				
Average value	0.2	0.7	6.1	2.6
Less than average by 20%	3.9	4.1	5.9	3.2
St. average by 20%	11.9	1.8	0.5	4.3
At the entrance of local treatment facilities				
Average value	0.0	0.2	1.5	0.4
Cleaning effect, %	100	71.4	75.4	84.6
Less than average by 20%	0.0	2.4	1.4	0.2
Cleaning effect, %	100	41.4	76.2	93.7
St. average by 20%	0.0	0.2	0.1	0.1
Cleaning effect, %	100	88.8	80.0	97.7

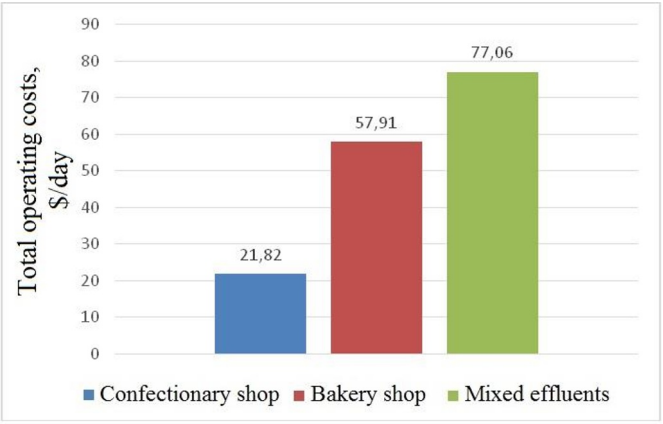


Fig. 3. Total operating costs for wastewater treatment plants for bakery production, confectionery production and mixed baking production.

It is important to note that wastewater treatment processes consume significant amounts of energy due to the need to provide optimal treatment conditions. Since issues of increasing energy efficiency are important for food production, then, as follows from Figure 2, at the development stage different options for the layout of treatment facilities should be considered, taking into account the predicted treatment effect.

4 Discussion

The main task of developing a technological scheme for treating wastewater from bakery enterprises is the selection of rational treatment methods based on the composition of the wastewater, the concentration of pollutants in the wastewater and the conditions of their formation. It is also necessary to consider the feasibility of designing complex treatment facilities or local ones for workshops or production areas, based on the predicted treatment effect, energy consumption and operating costs.

Since wastewater treatment is an important process in the food industry, the ratio of energy costs as part of treatment operating costs must be taken into account when designing and selecting the most energy-efficient option for local facilities.

The arguments in favor of using local treatment systems are the following:

- Enterprises, as a rule, are located in urban areas in densely built-up conditions and therefore several small built-in cleaning systems can be placed on their territory, while one complex structure requires a significant area and its placement is not possible.
- There is no need to treat household wastewater if it is sewered separately and supplied to municipal wastewater treatment plants.
- Existing experience in operating treatment facilities shows that it is easier to treat wastewater contaminants that are homogeneous in composition than heterogeneous complex mixtures.

Arguments against local treatment facilities may include additional investment costs for each workshop if the enterprise produces baked goods from wheat and rye flour, as well as small baked goods using yeast, and confectionery products, and it produces mixed wastewater.

5 Conclusion

Tightening standards for wastewater discharge and the state of treatment facilities require food manufacturers to improve existing treatment systems or introduce new schemes, while justifying the choice of technology at the development stage becomes a very urgent task. As the results of the simulation experiment show, using the GPS-X application software product, it is possible to obtain recommendations for choosing the layout of local treatment facilities and simulate deviations from normal operating modes, checking the system's response to deviations. In the future, it is planned to simulate the system response with a random selection of treatment quality indicators at the entrance to local treatment facilities based on the Monte Carlo method.

To verify the results of simulation modeling, testing will be carried out using model solutions in experimental installations - physical models of settling tanks and flotation tanks. The possibility of experimenting on real wastewater at food production enterprises at this stage is problematic, since the lack of sensors for automatic control of the studied wastewater parameters, flow rate and other elements of digital monitoring can become a serious problem for testing models in real conditions

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