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# Applicability of biological wastewater treatment for various industries

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**Abstract.** Biological treatment methods are used to remove organic and some inorganic substances from wastewater using the simplest organisms that use these substances for nutrition, breaking them down using cellular processes. The article deals with the aerobic, anaerobic and anoxic stages of biological wastewater treatment. Their differences are explained and the best way to use biological processes is analyzed according to the type of industry/production. At wastewater treatment plants, anaerobic treatment is often used at first to remove a significant part of organic substances from wastewater before sending them for further aerobic treatment. Aerobic treatment is effective for various types of wastewater, especially with lower biochemical oxygen demand (BOD) and chemical oxygen demand (COD). A comparative analysis of wastewater composition from food, oil and gas processing, pharmaceutical and pulp and paper industries was carried out. In the presence of organic compounds, the technology is chosen depending on the total organic matter content or the total COD content, which characterizes the total organic matter in water. A combination of anaerobic and aerobic methods is possible, if a discharge into the sewer system or into water bodies is required. The grounds for the application of biological wastewater treatment of these industries are given.

## 1. Introduction

The problems of wastewater treatment are becoming more and more acute every year. There are more and more industries, and in this regard, the need for water resources for the optimal operation of the production process is increasing. The difficulty lies in the huge variety of impurities in the effluent, the composition of which changes frequently (during the day, month, and even the season).

Biological treatment methods are used to remove organic and some inorganic (for example, hydrogen sulfide, sulfides, ammonia, nitrates, etc.) substances from wastewater using the simplest organisms that use these substances for nutrition, breaking them down using cellular processes [1,2]. Biological wastewater treatment is a complex set of activities at the intersection of biology and biochemistry. Its purpose is to create a system, where the cleavage products can be easily collected for disposal or recycling. Biological treatment is an important and integral part of any wastewater treatment plant that treats both municipal wastewater and industrial wastewater. It is used all over the world because it is the most efficient and economically advantageous in terms of capital and operating costs over other treatment processes [3,4].

Biological treatment can be represented by aerobic and anaerobic processes. Aerobic occur in the presence of oxygen, and anaerobic is in the absence of oxygen. Presently, improved technologies have been developed to control aerobic and anaerobic biological processes for optimal removal of organic



matter from wastewater [1,5]. There are three variations of biological treatment: anaerobic, anoxic and aerobic.

## 2. Methods

### 2.1. Anaerobic process

The first stage of biological wastewater treatment, which takes place in anaerobic reactor, is treatment under anaerobic conditions or biological phosphorus removal. Its purpose is to eliminate organic compounds while reducing phosphates [5].

Biological phosphorus removal occurs as a result of assimilation by polyphosphate accumulating organisms (PAO). PAO are bacteria that, under certain conditions, are capable of consuming polyphosphates from wastewater and storing polyphosphates inside the cell. A necessary condition for the implementation of biological phosphorus removal is the presence of an anaerobic and aerobic reactors.

In the anaerobic reactor, polyphosphate accumulating organisms use the energy of the polyphosphate hydrolysis reaction to absorb decomposition products that accumulate as energy reserves of the polyhydroxyalkanoate. In this process inorganic phosphorus is released into the substrate. Also, at this stage the accumulation of fatty acids occurs [4,5].

In the aerobic reactor, the accumulated energy of polyhydroxyalkanoate is released, and inorganic phosphorus is assimilated in the biological cell and stored in the form of polyphosphate inclusions. Polyphosphate accumulating organisms absorb more phosphorus under aerobic conditions than excreted under anaerobic conditions. As a result, phosphorus concentration in polyphosphate accumulating organisms increases, while phosphorus concentration in wastewater decreases [6,7].

At the anaerobic stage there is no oxygen in the wastewater. Most of the return activated sludge moves from the secondary clarifier, is mixed with special mixers or submersible flowmakers – they are necessary so that the sludge mixture is constantly in suspension. If the sludge settles, stagnant zones will appear, which will lead to a disruption of the process – the development of the wrong biocenosis, which is needed, or to the death of the sludge [8].

### 2.2. Aerobic process

Bacteria play the main role in the oxidation of organic and some inorganic impurities in wastewater. Their total number in activated sludge reaches  $10^8 - 10^{14}$  cells per 1 g of dry matter [9]. Maintaining the activated sludge in suspension, as well as maintaining the required direction of the liquid in this zone, is also ensured by mixers and submersible flowmakers. Air supply is carried out using blowers located separately from the tanks, as well as aerators. Compressed air is supplied through the air duct through the aeration elements located at the bottom of the tank. The air passes through filter plates or perforated pipes and, like in a shower, is "sprayed" into small bubbles. The smaller the bubble, the better the oxygen is absorbed [4,5].

Aeration is necessary to provide microorganisms with a sufficient amount of oxygen, as well as to prevent sedimentation of activated sludge [4]. The work of the mixers generates such an energy flow that does not allow air bubbles to quickly rise to the surface of the water. Due to this, the contact time of water and air increases, therefore, the efficiency of the entire treatment system improves. There is a process of nitrification – ammonium nitrogen is oxidized to nitrates [5]:



Organic matter consumed by microorganisms is oxidized to water, carbon dioxide and nitrogen. There is also an increase in the number of microorganisms as a result of reproduction (activated sludge). Part of the activated sludge and a large amount of nitrates are sent back to the anoxide zone as return activated sludge to maintain a sufficient concentration of microorganisms in the wastewater for the complete treatment process. Another part of the treated wastewater enters the secondary clarifier [4].

### 2.3. Anoxic process

The sludge mixture containing sufficient nitrates comes from the aerobic reactor to the anoxic reactor. The treatment purpose in this reactor is to remove nitrates and reduce the BOD coming from the aerobic reactor. Microorganisms use aerobic oxidation as an energy source. They absorb the oxygen in nitrates. In this way, gaseous nitrogen is generated and released into the atmosphere [5].

## 3. Results and discussion

### 3.1. Wastewater treatment at food enterprises

For most food enterprises, the main pollutants are organic substances, as a result of which such effluents have high COD, BOD and a high content of suspended solids, dry residue and fat (Table 1) [10]. At food enterprises, sources of organic matter are, directly, raw materials, manufactured products that enter wastewater, usually in the process of CIP washing (specialized CIP (Cleaning In Place) station designed for washing various technological equipment, washing out the product from hard-to-reach places, disinfecting non-separable parts), pipelines where manual flushing is impossible), as well as waste resulting from the processing of organic raw materials (serum, yeast, blood, etc.), i.e. not only expired products, but a part of raw materials that is illiquid or not in demand [11]. These wastes (wastewater) are treated using biological methods. A combination of anaerobic and aerobic methods is possible, if a discharge into the sewer system or into water bodies is required [12].

**Table 1.** Wastewater composition from various industries [13]

Parameters	Suspended solids, mg/dm <sup>3</sup>	pH	Dry matter, mg/dm <sup>3</sup>	COD, mgO <sub>2</sub> /dm <sup>3</sup>	BOD, mgO <sub>2</sub> /dm <sup>3</sup>	Fats, mg/dm <sup>3</sup>
Brewery	600	7	3000	1500	1000	—
Malt	100	6	500	300	200	—
Non-alcoholic drinks	320	8	2000	1000	700	—
Grain alcohol	440	5.8	500	600	290	—
Potato alcohol	550	6	800	1350	430	—
Fodder yeasts	520	6.5	600	1600	620	—
Distilled beverages	250	10	1000	120	—	—
Slaughter houses	2300	7.5	1600	4500	2500	1200
Dairy industry	350	8.5	3500	3500	2000	5100
Baking industry	150	6.9	900	680	450	—

In the presence of organic compounds, the technology is chosen depending on the total organic matter content or the total COD content, which characterizes the total organic matter in water [14].

With a COD < 3 000 mg/l and the absence of fats (organic substances are completely dissolved), it is worth choosing aerobic treatment methods, achieving the discharge requirements to the sewage system or water bodies. For example, this method can be used in breweries, starch production, in the alcohol industry, where there are no fats, but there is a large amount of dissolved organic matter [5,14].

At a COD > 3 000 mg/l, with the presence of fats, for concentrated industrial effluents, the use of aerobic treatment methods is unreasonable and requires high energy consumption for air supply. At high concentrations of organic substances, more complex purification methods are required using complex technologies of anaerobic and aerobic methods [14].

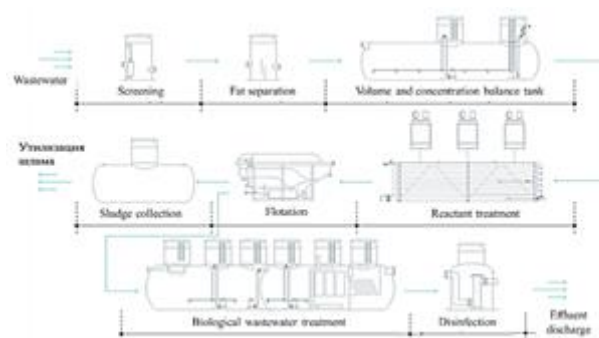
At dairy, meat and fat industries, suspended solids and fats are present in wastewater, which are separated at the preliminary treatment stage – at the flotation stage. At present, grease traps are widely used to separate fat from wastewater. Biological treatment focuses on the recycling of organic matter. After flotation, excluding the undissolved component, the COD is reduced by about 30-40%. If, as

before, the dissolved component in water has high concentrations of organic matter, then in practice anaerobic stage is added to the aerobic stage (Figure 1) [5,15].

The main enterprises where anaerobic technologies are most often used or found:

- meat production (wastewater contains a lot of blood, high COD, and phosphorus) [7,8,16];
- drinks production (for example, production of sweet drinks, where there are sugars, that is, there are organic substances) [17,18];
- breweries (use of aeration tanks, the main treatment stage is anaerobic reactor) [18,19];
- dairies, cheese factories (anaerobic reactors are recommended to be used when the enterprise produces cottage cheese, cheese, because of whey and the COD increase to 10 000 mg/l). Whey significantly affects the overall composition of effluents, even if the enterprise has local systems for concentrating whey using membranes, drying. Part of the whey during SIP-washing is supplied to the treatment plant, and permeate (pure water that has passed through the membrane) can also be discharged after concentration to the treatment plant. Unequivocally, if a company produces cheese or cottage cheese (there is sour or sweet whey), then even taking into account the fact that the company has systems for its local processing and mainly does not discharge it to treatment plants, the COD usually ranges from 4 000 to 6 000 mg/l. If whey is discharged to treatment facilities, then, of course, COD can reach more than 10 000 mg/l [20];
- deep processing of grain, production of starch, lysine, citric acid [21];
- production of alcohol, disposal of stillage after alcohol, wineries [22];
- sugar production [23];
- fruit processing (for example, the production of jams has a high organic content) [24];
- confectionery enterprises (those that contain some ingredients – caramel, fillers, where the organic concentration is quite high) [25];
- coffee production (in the production of tea, on the contrary, an anaerobic reactor is not required) [26].

Organic substances with high levels of COD and BOD at treatment plants must go through certain decomposition stages. If there is anaerobic treatment, these stages are divided into four parts: the process of hydrolysis (acidification with the formation of fatty organic acids) takes place in the blending tank, acidogenesis, acetogenesis, and methanogenesis in the anaerobic reactor. Each stage has its own specific microorganisms that must be controlled. The presence of calcium content is also important [5].



**Figure 1.** Steps of wastewater treatment from slaughter houses [6].

A massive increase in activated sludge biomass after aerobic treatment occurs at wastewater treatment plants where there is high content of fat (dairy plants, cheese plants, dairy enterprises). This excess activated sludge is flake-like, light. The ability of activated sludge to form well-settling flakes

is its most essential property since the efficiency of treating wastewater in aeration tanks largely depends on the subsequent process of separating activated sludge from effluent. When operating aeration tanks, a big drawback, which sharply disrupts the entire treating process, is the "swelling" of the activated sludge [5,27]. One solution to this problem is the use of granular activated sludge in the wastewater treatment plant. It differs from the usually activated sludge in its biological composition (it simultaneously includes filamentous bacteria and flocculants - bacteria to *Pseudomonas* of the genus *Zoogloea*), physicochemical composition – COD up to 7000 mg/dm<sup>3</sup> (at a pH in the range of 7.0-8.5), and most importantly it is denser, with large particles that settle at a higher rate [4,9]. It leads to the minimal formation of excess biomass, increases resistance to increased pollution; increases treating efficiency at lower energy costs.

The specific structure of activated sludge imposes specific requirements for the operation and effective type of anaerobic reactor. Reactors that operate in distilleries and breweries operate with one type of activated sludge (this is granular activated sludge), while dairies encounter conventional activated sludge (light, flake-like) and are more complex to undergo biological wastewater treatment [14].

The composition of wastewater and the type of production are taken into account when choosing a particular treatment method.

### *3.2. Specific wastewater treatment*

At the enterprises of the oil refining or gas processing complex that have sulfur-alkaline effluents (pH >7), against the background of the total amount, the share of hazardous chemicals may occupy only 1-1.5%, but they are so concentrated that their disposal is extremely difficult. All these wastewaters have a high content of organic substances (COD can reach 200 000 mg/l), petroleum products, and sulfides.

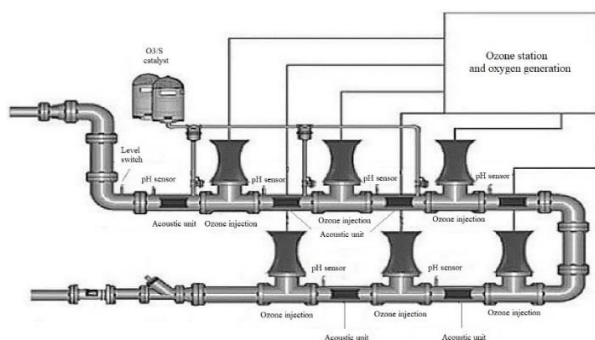
Accordingly, these waters cannot be treated by the conventional biological wastewater treatment because they are toxic and suppress biological purification; using adsorption processes is also extremely difficult because their concentration is quite high and a large amount of coal loading is economically required, which will often have to be regenerated and replaced. There are oxidation processes using ozone, but it additionally requires high economic costs (electricity in the first place).

The same effluents can be present in the paper production (concentrated wastewater with a high organic content), sulfur compounds with chlorine as a result of cooking processes (sulfites, sulfates depending on the technology used) and paper bleaching (chlorine-containing compounds), pharmaceuticals (chemical production of several components using substances that are resistant to biological degradation) [28].

The waste type of oil refineries depends not only on the production itself, but also on the raw materials which used in enterprise process, since oil differs in composition and quality, and, accordingly, different types of waste are obtained (various sulfide-alkaline wastewater: sulfide, naphthenic, phenolic). Some oil products can be removed using an oil tank - a type of treatment plant that has a fairly simple, convenient, and practical design. Its action is based on the principle of different densities of water and refined products [30].

Formally, there is a technology for each of the components, but when mixed, it turns out that biological wastewater treatment allows to remove organic matter, but at the same time there are other substances that at the same time kill biocenosis. For example, if sulfides are to be removed, oxidation processes are required, which are also spent on organic substances.

The technological solution, in this case, is deep oxidation processes, which make it possible to significantly reduce the organic component (up to 90-95%) and all hazardous substances (sulfides, sulfites, mercaptans, phenols, etc.) and to the concentration that will be permissible for its treatment at sewage treatment plant. All wastewater enters the pipe, and the processes of ultrasound and ozone dosing cycle (the more these circles, the more efficient the treatment is) (Figure 2).



**Figure 2.** Process diagram of special wastewater treatment [31].

In the general scheme, this is as follows: streams are processed in the storage tank, then flotation takes place, and then a biological wastewater treatment process. Such promising technology is safe, compact, does not require the generation of waste. There is a certain amount of carbon dioxide that is spent on oxidation processes because during oxidation carbon is an acceptor in this reaction, sulfides go into sulfate form, which is safe for the biological wastewater treatment process. Conventional treatment methods, on the contrary, require catalytic waste incineration, which is accompanied by additional operating costs, the absence of the possibility of water reuse, and the formation of unpleasant odor [31].

#### 4. Conclusions

Thus, anaerobic processes are highly effective for wastewater treatment containing a high concentration of organic substances. That is why at wastewater treatment plants, anaerobic treatment is often used at first to remove a significant part of organic substances from wastewater before sending them for further aerobic treatment. These two methods are also effective independently of each other. Anaerobic treatment is ideal for various types of wastewater, including agricultural, food, pulp and paper, textile, household wastewater.

Aerobic treatment is effective for various types of wastewater, especially with lower biochemical oxygen demand (BOD) and chemical oxygen demand (COD). It is used for wastewater treatment of chemical, industrial, food, oil, and gas, as well as the municipal industry. In some cases, the combination of anoxic, aerobic, and anaerobic processes is ideal for wastewater treatment as it helps to reduce sediment formation. Activated sludge is often necessary for wastewater treatment, but reducing its volume can reduce the capital and operating costs of the enterprise.

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