Vol. 3, No. 2, 2018

ENHANCEMENT OF ENVIRONMENTAL SECURITY OF DESTRUCTION PROCESSES OF WATER POLLUTANTS IN ECOSYSTEMS OF WATER TREATMENT PLANTS

Tetyana Rotay

Postgraduate student of the Department of Biotechnology and Bioengineering,
Kremenchuk National University named after Mykhailo Ostrogradskyi
20, Pershotravneva Str., Kremenchuk, 39600, Ukraine
v-nik@kdu.edu.ua

Received: 02.08.2018

© Rotay T., 2018

Abstract. At present, mechanical, chemical, biochemical and physicochemical methods of cleaning are developed and efficiently used to protect water bodies from sewage pollution. The methods of biochemical wastewater purification from organic contaminants with the use of activated sludge have received the highest recognition. Getting of additional nutrients (nitrogen, phosphorus, potassium) and other trophic precursors into the aquatic ecosystem directly leads to immediate biohydrogenase reaction of increase in the number and biomass of the primary producers of organic matter. Chemical composition of water is an important criterion for water quality assessment. Therefore, the study of the dynamics of qualitative and quantitative chemical composition of water is a priority task in determining the efficiency of wastewater treatment in bioreactors.

Key words: sewage, activated sludge, microhydrobionts, organic substances, destruction

1. Introduction

Pollution of the natural environment causes qualitative changes in the main components of nature and their constituents and negatively affects living organisms. The level of changes in the natural environment depends on two main factors: the intensity of the manifestation of the material nomenclature of pollutants and the ability of nature to self-purification. In the process of long-term exposure of pollutants, the main natural, socio-economic functions of the natural environment deteriorate or are violated. This complicates the lives of all living organisms, and especially humans.

An urgent problem is an increase in the concentration of nutrients in sewage, in particular, phosphorus, nitrogen, and others. The most common method of removing phosphorus compounds is the biological one, since physical, chemical and physico-chemical methods have a number of significant drawbacks in terms of the operation of structures and the economic orientation of the use of one or another method. At present, different schemes are used in practice, which include a combination of biological process and chemical deposition. Such combination of processes allows gettig purified water of higher quality than while using one of these methods [1].

Since the number and concentration of wastewater discharged into the urban sewage system is constantly increasing, and the process of cleaning is carried out on obsolete equipment, the ecological safety of water objects is very low. The processes that occur in the biological treatment of wastewater require constant monitoring of parameters used for technological purposes. Traditional cleaning methods, as a rule, do not allow us to obtain the required degree of purification and achieve effluent treatment quickly enough. Therefore, it is necessary to upgrade the existing treatment facilities.

The theoretical methods of investigation of technological processes have an exceptional value, since their results can be used to solve a number of technological problems. However, these methods are very time-consuming and expensive, which reduces the effectiveness of their use [2].

The vast majority of methods for intensifying the purification process require additional stages, and, consequently, the construction of new treatment facilities, the availability of free areas, increased costs of material, energy, financial and other resources, which in the current economic conditions has virtually no prospects. Thus, the solution of the problem of increasing the efficiency of sewage treatment should be based on the development of new methods of intensification, suitable for implementation at the existing treatment plants. Different methods, such as structural and technological changes in wastewater treatment plants, immobilization of active sludge on loading materials, diverse effects on active sludge, which results in the destruction of biomass cells, are used to improve the efficiency of biological wastewater treatment, and thus, it allows intensifying the processes of vital activity of sludge microorganisms.

The aim of the work is to find the most effective method for the destruction of active sludge, which will make the removal of contaminants from wastewater more intensive, increase the degree of purification and the amount of excess biomass.

2. Materials and methods

With high levels of organic matter in sewage, aerobic bacteria requiring oxygen for their vital activity are rapidly multiplying. The process of enzymatic destruction of organic rehydration is called biochemical oxidation. Contacting with organic compounds of wastewater, aerobic bacteria convert them into chemically safe substances (water, carbon dioxide, nitrite, nitrate and sulfate ions, etc.) and partially consume them to build their own biomass. The amount of biochemical oxygen consumption (BSC) is numerically equal to the concentration of O_2 in mg / l or in g / m^3.

The BSC indicator characterizes the amount of oxygen needed by microorganisms for the biochemical oxidation of organic substances – pollutants of sewage with the formation of CO_2 and H_2O for a certain time (for example, for 2, 5, 20 days – BSC_2, BSC_5, BSC_{20}). In particular, BSC_5 represents an important ecological indicator of natural reservoirs in biochemical oxidation of organic substances within 5 days prior to the beginning of nitrification.

BSC is an indicator that reflects the biochemical consumption of oxygen by organic microorganisms in the period necessary for the complete conversion of pollutants into final products (without taking into account the process of nitrification).

BSC of untreated sewage can exceed the sanitary norms (100–3000 mg O_2/l and more). For a more complete assessment of the content of organic substances in sewage (in particular, the mixture of domestic and industrial effluents), besides BSC, the index of chemical consumption of oxygen (CHC) is used.

It characterizes the total content of organic and inorganic substances in wastewater on the basis of the cost of chemically bound oxygen (mg O_2/l), reflecting the amount of oxygen in various chemical oxidation agents (a mixture of sulfuric acid with potassium iodate or chromic acid), which is consumed during the heating process in order to oxidize pollutants of sewage, including those recovered during nitrogen nitrification.

Chemical oxygen demand (COD) is one of the main integral indicators of anthropogenic pollution used to control the quality of drinking water and natural sewage of different nature.

Biochemical activity of microorganisms in the biocenosis of treatment plants is associated with their biochemical activity, that is, the rate of decomposition of organic contaminants in wastewater. To determine it, a relative biochemical indicator BSC / CHC is used. Biochemical oxidation is possible when the ratio of BSC / CHC • 100 = 50 %. The main requirement here is the absence of toxic substances and impurities of heavy metal salts in the sewage.

The process of oxidation of organic substances in sewage is a consistent series of complex biochemical transformations in the cells of microorganisms. Initially, microorganisms adapt to the presence of various chemicals and the gradual changes in their concentration. The duration of the adaptation period depends on the specific conditions and ranges from 1–2 days to several months.

Substances dissolved in the medium reach the surface of microbial cells and penetrate into them due to convective and molecular diffusion through the semi-permeable cytoplasmic membranes. Diffusion is the result of the occurrence of a gamma-concentration of substances in the cell and around it. However, a significant part of the substances enters the cells through a specific soluble protein complex. It involves the formation of a carrier substance that can then pass through the membrane into the cell cytoplasm, where it is enzymatically destroyed, and again into a new transfer cycle.

The biocenose formed in the structures of biological wastewater treatment (for example, a bio-film on the carrier of the bio-filter) includes a set of microorganisms, lower plants and animals which are interconnected with the conditions of compatible vital activity. The system of biocenosis includes single-celled bacteria, actinomycetes (radiant fungi), algae, yeast (water fungi). They are characterized by enzymatic activity to any type of contaminant present in the drains. The source of nutrition for these microorganisms is substrate compounds (contamination) that decomposes them to simple substances. The simplest ones are nutritional elements for worms (cobblestones, nematodes) and insect larvae.

The maintenance of a certain ratio of biomass in the system of treatment facilities can provide stability of the sewage purification and neutralization of the pathogenic microflora in it.

It should be noted that extremely high metabolic activity is characteristic to bacterial cells in which two interrelated metabolic processes are very intensive – decay of molecules (catabolism) and their synthesis (anabolism). Under the influence of appropriate internal enzymes in bacterial cells, the destruction of complex organic molecules leads to the formation of low molecular weight fragments (monosaccharides, amino acids, fatty acids, etc.) from which their own cellular structural proteins, fats and carbohydrates are then synthesized, cells grow and multiply.

The biological method of purification allows destroying various organic compounds which include carbon, hydrogen, oxygen, nitrogen, sulfur and phosphorus using the activity of enzyme systems of living organisms. Destruction of complex organic molecules is accompanied by the simplification of their structure by splitting off individual fragments. Many of the impurities present in domestic and industrial wastewater completely decompose during the biochemical transformation. In addition, biochemical treatment can also be used to oxidize and restore complex compounds with further removal of heavy metals of variable valency (ferrum, manganese, chromium and mercury).

Depending on what substances are acting as an acceptor of hydrogen, the processes of biochemical oxidation of the substrate by microbial cells are divided into three main groups, namely:

– cellular respiration, if the hydrogen acceptor is oxygen (aerobic conditions);

– biochemical oxidation – the process of splitting organic compounds;

– fermentation (anaerobic conditions) when an organic ingredient or anaerobic respiration acts as the hydrogen acceptor, if the hydrogen acceptor is an inorganic agent such as sulfates, nitrates and the like.

The process of aerobic oxidation proved to be the most effective. It allows microorganisms to receive more energy and to provide environmentally safe low molecular weight substances (carbon dioxide and water) into the aquatic environment.

Energy metabolism occurs with the synthesis of the main carrier of biological energy – the coenzyme ATP (adenosine triphosphate). Ultimate low molecular weight water-soluble metabolism products are excreted from the cell into the substrate. In other words, there is a consistent and directed mass transfer between the cell and the aquatic environment which involves the receipt of nutrients and the timely removal of metabolic products. Aerobic organisms are capable of significantly more efficient ATP forming by phosphorylation via the electron transport chain and the ATP-synthetase enzyme (carrying out the so-called tissue respiration).

The process of breathing, that is, the generation of energy, takes into account the release of recovered equivalents, in particular protons (hydrogen atoms) and electrons. The latter are formed as a result of the oxidation of organic matter of the substrate (sewage) and the regeneration of ATP. In this case, the cells of microorganisms receive vital nutrients essential for life (carbon, nitrogen, oxygen, hydrogen and phosphorus), as well as trace elements: iron, manganese, sulfur, potassium, and others. If the biogenic elements are insufficient, they are additionally added to the waste water in the form of additives.

In practice, the processes of aerobic and anaerobic biochemical wastewater treatment have become widespread. The main purpose of aerobic purification methods is the oxidative mineralization of carbon-containing organic compounds and the transformation of reduced forms of nitrogen into oxidized (nitrification of nitrogen with the formation of nitrite and nitrate ions).

Aerobic biochemical purification of wastewater from organic compounds is carried out with the participation of heterotrophic microorganisms, for which organic carbon (proteins, fats, carbohydrates, etc.) is the source of nutrition. The nutritional value of carbon manifests itself in different ways and depends on both physical and chemical properties of the above-mentioned organic substances of sewage, and on the physiological characteristics of microorganisms. In the process of microbial vital activity, a portion of carbon atoms is oxidized first to carbonic acid ($-CO_2$), and then to carbon dioxide. Part of carbon atoms is reduced to the radicals CH_3-CH = CH-, which are part of the cell.

Microorganisms that oxidize carbon live in the upper part of the treatment reactor, and nitrification bacteria are in the lower part of it, where there is more competition for oxygen and nutrients. The biochemical degradation of proteins into individual amino acid molecules containing functional carboxylic (- COOH) and amino group (- NH_2), combined with a carbon atom, as well as the carbon radical R, are catalyzed by proteolytic enzymes. Under the action of exoferment chains, amino acids are cleaved and converted to a state convenient for absorption by cells. As a result of intracellular processes of amino acids with the participation of endoenzymes, they are further destroyed by the release of free ammonia (the process of ammoniation).

It is also customary to divide aerobic methods according to the type of reservoir in which the oxidation of pollutants occurs. Bioengineering structures (BIS) in the form of biological ponds, as well as special devices – biofilters and aerotanks can be used as reservoirs. Aerotanks are refered to as homogeneous bioreactors. Purification of water in the aerotank occurs in the process of passing through an aeration mixture of sewage and active sludge.

Active sludge is characterized by a lamellar structure, representing a set of microorganisms (filamentous bacteria, nitrification bacteria) and protozoa (infusoria), with a set of enzymes for the removal of pollutants from wastewater. The purification process in aerotanks is a continuous fermentation of harmful substances. On the one hand, the particles of active sludge, formed by filamentous bacteria, make an adsorption skeleton, around which flocculates appear, and on the other hand, they prevent the formation of foam and stimulate deposition. The simplest, absorbing bacteria reduce turbidity of drains.

Thus, filamentous bacteria which are in the flocculent mixture of active sludge destroy organic substances and ensure their rapid deposition in settling stations, where compacted sludge is formed. The role of nitrification bacteria (Nitrosomonas, Nitrobacter) is reduced to the oxidative transformation of reduced forms of nitrogen.

The supply of air to the aerotank is regulated on the basis of the assessment of the quality of the wastewater at the exit from aerotanks, taking into account the concentration of dissolved oxygen and active sludge in it. If the quality of the waste water at the exit from aerotanks does not meet the established requirements, then at high deficiency of dissolved oxygen, the supply of air is increased, and at high concentration of dissolved oxygen, the concentration of active sludge is increased (if it is possible under the conditions of secondary tanks). If at the maximum possible concentration of active sludge and the standard concentration of dissolved oxygen the quality of the purified sewage does not meet the established requirements, this indicates that the loading of the structure behind the BSK exceeds its oxidizing capacity.

The average annual efficiency of sewage treatment in a bioreactor according to BSC_5 is 97.37 %, and the maximum of 97.6 %, which is a testimony of rather high results.

The concentration of dissolved oxygen in the wastewater is determined in the sample taken with the molten active sludge, or according to the indications of the automotive devices. In the case of changes in the chemical composition of sewage and increase in their toxicity, the load on a part of aerotanks is reduced to allow microorganisms of the active sludge to adapt to the new composition of sewage. In the case of complex violations of the sewage treatment regimes in aerotanks, the active sludge loses its purification ability. The spoiled sludge is removed from the system and new active sludge is cultivated.

Maintenance of sludge and oxygen regimes in a multifunctional bioreactor is very important for the effective operation of the treatment facilities.

The processing of experimental data suggests that there is a parabolic relationship between the silt index (characterizing sedimentation properties of sludge) and the load on active sludge. It is known that the smaller is the value of the silt index, the more efficient is the separation of sludge and purified water in secondary sedimentation that is why it is necessary to maintain certain loads on active sludge. Therefore, the optimal values of the silt index at optimal loads on active sludge are determined.

The concentration of dissolved oxygen in the sludge mixture is one of the main factors that ensure the effective conduct of the biological treatment of wastewater from pollution. According to the design documentation, the concentration of dissolved oxygen along the length of the aeration zone of the bioreactor should be not less than 2 mg/dm^3. The real value of oxygen concentration in a bioreactor depends on the ratio of the rates of its dissolution and absorption by the silt microorganisms.

The supply of oxygen is regulated in the automatic mode by switching on the additional blower equipment with a decrease in its content in the bioreactor. When high-concentration wastewater gets into the bioreactor for purification, there is a significant decrease in the concentration of dissolved oxygen, and the most intense wastewater treatment is carried out.

During the selection of hydrobiological samples from an aerobic-anaerobic bioreactor and their study using light and electronic microscopes, the species composition and systematic structure of dominant species of microfauna are determined, due to which the so-called active sludge in the bioreactor is formed. The taxonomic spectrum is represented by four types (*Sarcomastigophora, Ciliophora, Annelida* and *Nemathelminthes*), which include 25 species, 13 of which are dominant, from eight classes and fourteen rows of single and multi-cellular animals.

3. Results

The results of the preliminary analysis of the frequency of occurrence of active sludge species allow making the following conclusions:

– the most common are all simple samples: *Arcella vulgaris, Aspidisca costata and Uronema nigricans*, the rate of occurrence of which is 27.8, 20.4 and 19.4 %, respectively;

– optional anaerobic species that serve as the main treatment of the sewage in a bioreactor, in addition to the first three, include: *Peranema trichophorum, Philodina roseola and Vorticella convallaria*;

– optional aerobic species, which perform the function of biological wastewater treatment, include: *Centropyxis aculeate, Vorticella campanula* and *Bodo angustatus*.

The next step was to determine the overall occurrence coefficient for dominant species.

During the second stage of the research, the indicators of quantity, biomass, occurrence and fertility index for each of the identified types of microfauna of the bioreactor of wastewater treatment plants were determined and reduced to the matrix.

Thus, the indicators of the species composition of the dominants, the number, the biomass, the coefficients of occurrence and the index of saprobity of the microfauna of the bioreactor of the treatment facilities directly determine the level of intensity of the processes of bio-waste of wastewater, which occur due to “active sludge”.

At the final stage of the research, the results of the correlation of the acidity and nitrogen utilization rates at the entrance to the bioreactor and its exit were analyzed. During the study of structural and functional organization of the ecosystems of biological ponds it was necessary to determine the balance between the production and destruction of organic matter. To do this, a new coefficient of relative nitrogen utilization (K_N) by different groups of bacteria was proposed.

This coefficient reflects the mass ratio of nitrogen in ammonium, nitrite and nitrate forms. The value of $K_N > 1$ indicates a low level of ammonia nitrification, which is mainly a product of the hydrolysis of amino acids, which is observed in sewage until it reaches the bioreactor. Weak acid reaction of sewage in general (pH <7.0) causes the hydrolytic conditions of the decomposition of proteins.

After sewage passing through the bioreactor, in most cases, reverse processes are recorded: K_N values are less than one, indicating the low activity of the processes of protein ammoniation, which may be due to the excess of nitrogen-containing organic substances (for example, proteins, proteids, in particular, albumin, casein and caseinogen, aminosaccharides, etc.), small numbers (biomass) of rotting, in particular methanogenic, or high-activity of nitrifying bacteria. Usually, these processes occur in slightly alkaline conditions (pH > 7.0).

Thus, comparing the influence of different methods of wastewater treatment in the application of sludge destruction, it can be concluded that chemical and mechanical disintegration yields rather high results. Destruction of active sludge as a result of chemical and mechanical disintegration proved to be a very effective way to improve the quality of sewage treatment.

Conclusions

The use of bioactive processes in biomass destruction of active sludge opens up new possibilities for biological purification. The most effective method of destruction of active sludge for the biological treatment of wastewater is the use of mechanical and chemical disintegration, in which there is an increase in the degree of wastewater treatment.

References

[1] Vasilyuk T. P. The effect of sewage treatment with a biological method using plants of the species Eichornia crassipes Martyus for different hydraulic loads. / T. P. Vasilyuk // Biotechnologia Acta. – 2009. – T. 2. – No. 1. – S. 99–106.

[2] Use of hydrobionts of the species Eichornia crassipes for sewage treatment / T. P. Vasilyuk // Ecology of the environment and safety of life. – 2008 – No. 4. – P. 63–68.

[3] Vinberg G. G. Biological ponds in wastewater treatment practice / G. G. Vinberg, P. V. Ostapenya., T. N. Sivko, R. I. Levina, ed. Ostapenya P. V. – Minsk: “Belarus”, 1966. – 231s.

[4] Efficiency of purification process in aerotank using methods of destruction of active sludge / Yu. M. Sadova // Ecological safety. – 2011. – No. 2. – P. 87–92.

[5] Zhmur N. S. Technological and biochemical-eprocesses of wastewater treatment in structures with aerotanks. – Moscow: AKVAROS, 2003. – 512 p.

[6] Zapolsky A. K. Water supply, drainage and water quality. – K.: “Higher school”, 2005. – 671 p.

[7] Shevchenko T. A. Combined method for removing phosphorus from domestic sewage // Improving the efficiency of use of water, heat and energy resources and environmental protection: 3b. Theses of the International Science. Practice Conf. Young scientists and students. – K.: KNUBA, 2008. – S. 40–43.

[8] Cheng B. Y., Liu T. C., Shyu G. S., Chang T. K., Fang W. T. Analysis of trends in water quality: constructed wetlands in metropolitan Taipei // Water Sci. Technol. – 2011. – Vol. 64. – No. 11. – P. 2143–2150.

[9] Seidel, K. Macrophytcs and water purification, in: Biological Control of Water Pollution. ,T. Tourbier, and R W. Pierson, eds., Pennsylvania University Press. Philadelphia. – 1996. – P. 109–122.

[10] Zimmles Y., Kirzhner F., Malkovskaja A. (2006) Application of Eichhornia crassipes and Pistia stratiotes for treatment of urban sewage in Israel. Journal of Environmental Management 81: 420–428.