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BIOTECHNOLOGICAL ADVANCEMENT OF NITROGEN AND PHOSPHORUS REMOVAL FROM CITY SEWAGE

The present report discusses the theoretical basis of nitrogen removal from wastewater, based on the processes of ammonification, nitrification, denitrification, and on a more recent direction called ANAMMOX-technology. The necessary conditions for this processes are considered. Biological phosphorus removal from wastewater through the proper use of microorganisms under different environmental conditions is noted. In this paper the recent advances of process design and operational optimization for nutrients removal are reviewed.

Increasing volatile fatty acids is the main direction for higher efficiency of biological removal phosphorus. Products fermentation of primary sludge or feeding in anaerobic and anoxic zones is used for increase of volatile fatty acids.

An important factor in increasing the degree of wastewater treatment with simultaneus lowering of energy costs is preliminary contact of initial sewage to circulating active silt in the conditions of aeration. It has been suggested to use a step feed denitrification and technology with cycling zones for lowering the energy consumption.

Anaerobic, anoxic and oxic zones were designed and constructed in a single reactor. Although the volume of the reactor was limited and the capability of the process in this reactor was reliable, it has a very good efficiency for removing phosphorus from raw wastewater.

The high MLSS of activated sludge, fixed microorganisms and application membrane techology are used for significantly increase of the capacity of plants while reducing their volume.

Key words: ammonification, nitrification, denitrification, biological phosphorus removal, acidification, lower energy consumption, immobilization, membrane.

Introduction. Eutrophication of natural waters is recognized as one of the most serious health problems for humans and animals: toxins produced by cyanobacteria in the algal ponds, are dangerous poisons, affecting the immune system. The main reason for the pollution of water with nitrogen and phosphorus is the discharge of municipal (urban) and industrial wastewater, in addition, the source of these elements is agriculture (fertilizers, animal waste) [1–4].

In Belarus annually 5,390 tons of ammonia, 200 tons of nitrogen nitrite and 1,120 tons of phosphate are reset into rivers with sewage. As a result, in most of the rivers on the territory of the Republic annual average concentration of ammonium nitrogen and phosphate phosphorus exceeds the maximum allowable concentration level [5].

Since the mid 80's of the last century the USA, EU, Japan, Canada and other developed countries began holding actions to prevent eutrophication of water bodies. On the one hand, the adaptation to the use of alternative non-containing phosphates detergents was hold, thereby reducing the content of total phosphorus in wastewater and urban sewage treatment plants by 30–40%. On the other hand, technologies for deep removal of nitrogen and phosphorus from wastewater were introduced [1, 6].

Sewage treatment plants in Belarus, mostly built in the 70–80-s of the last century, are mainly designed for the complete oxidation of organic pollutants with subsequent nitrification. Deep removal of nitrogen and phosphorus in such structures cannot be achieved [2]. Lately at the treatment facilities of the Republic it is increasingly common to use technological schemes based on the alternation of zones, designed for simultaneous occurrence of nitrification-denitrification and biological dephosphotation.

Main part. Biological treatment of waste waters from nitrogen and phosphorus based on processes of ammonification, nitri-denitrification (deammonification) and dephosphatization, is currently recognized the most economical and environmentally friendly.

Biological removal nitrogen from wastewater is held in the processes of ammonification (decomposition of organic nitrogenous compounds to inorganic ammonium), nitrification (the two step oxidation of ammonium compounds of nitrogen, first to nitrite, then to nitrate) and denitrification (bacterial recovery of nitrate nitrogen to molecular, accompanied by the oxidation of organic substances). It saves oxygen because the organic matter is oxidized not by dissolved oxygen but nitrate oxygen.

Biological treatment of wastewater from phosphorus compounds is held due to its removal with biomass of surplus activated sludge, which includes bacteria, that can accumulate phosphorus as polyphosphates in volutin granules, and the amount of accumulated phosphorus greatly exceeds the needs of bacteria themselves.

The processes of nitrification, denitrification and biological dephosphotation to certain degree is taken place in the traditional biological treatment facilities (aeration tanks), but in these structures, they require different conditions, sometimes contradictory.

To provide intensive processes of nitrification-denitrification and biological dephosphotation structure for the biological treatment is divided into zones with different levels of aeration (anaerobic, anoxic, aerobic). In these zones conditions conducive to the appropriate process should be created.

The intensity of occurrence of nitrification is influenced by temperature, concentration of ammonium nitrogen and oxygen, the pH value, the presence of inhibitors. Denitrification depends on the concentration of nitrogen substrate that is a source of energy, oxygen concentration, pH, temperature. The substrate must be easily oxidable, it can be internal (wastewater itself, filtrate from dehydration of excess sludge, supernatant liquor from the sludge thickener) or external (most common are methanol and acetic acid). Essential prerequisites of biological dephosphotation are alternate of anaerobic and aerobic conditions, the presence of easily available substrate [7].

Due to the variability of wastewater composition, cleaning conditions and the desired results a large number of technological schemes,their modifications, models describing the proceeding processes have been developed [8–11].

Autotrophic process Anammox. In world practice it is more common to find technologies based on the ability of autotrophic bacteria to oxidize ammonium nitrogen using nitrite as electron acceptor, the so – called Anammox process (Anammox – Anaerobic ammonium oxidation). This process is carried out by specific bacteria, which belong to phylogenetic group of eubacteria Planctomycetes.

In this process, molecular nitrogen is formed, but the major difference is that there is no need in any organic substrate, it is extremely important to remove nitrogenfrom wastewater depleted in organic contaminants. For the implementation of the Anammox process to remove ammonium nitrogen part of it must be oxidized to nitrite [12, 13]. These technologies are effective for the treatment of wastewater with high ammonium concentrations, including for treatment of return flows of wastewater after dewatering of digested sludge.

Currently in Europe and the United States about 40 sewage treatment plants are operating (or under construction) that use the technology of autotrophic oxidation of ammonium [14–16].

A major feature of the Anammox process is very low rate of bacterial growth and the consequent necessity of retaining them in the bioreactor. To achieve this goal various techniques are used: binding of bacteria on the load [17]; the gravitational or centrifugal sedimentation of sludge; flow in the bioreactor, wastewater, that don't contain organic substances to prevent the development of heterotrophic microorganisms; retention of bacteria carrying out the Anammox process due to the adhesion on the inner surface of the reactor and the formation of froth [18].

The acidification of raw sludge and wastewater with the purpose of increasing the concentration of volatile fatty acids. The main cause of instability of the process of biological removal of phosphorus is low maintenance and significant fluctuation in the concentration of easily oxidable organic compounds in the incoming wastewater. The low ratio of the concentrations of organic matter and ammonium nitrogen and phosphate phosphorus makes it difficult to use in wastewater treatment in Russia and Belarus technological solutions adopted in Western Europe and the United States.

Increasing the content of easily oxidable organic substances in the incoming for biological treatment wastewater is possible by filing them in the aerotank without prior settling or feeding in the anaerobic zone chemical compounds (methanol, acetic acid). Such measures lead to an increase in energy or operating costs.

The use of acidification (preferment.) raw sludge allows to increase the content of volatile fatty acids in the incoming for biological treatment waste waters, after which the wastewater enriched with volatile fatty acids, are served in the anaerobic zone. This technology is implemented at the Lyubersty wastewater treatment facilities of Moscow in 2009. For realization of this technology the operating modes of the primary clarifiers are changed: one part of the clarifiers perform the function of clarifying wastewater, the other part is transferred to a mode of compaction of the raw sludge. Drain water from tanks seals containing the products of the acidification together with the clarified water is sent to aeration tank, the content of volatile fatty acids in water increases with 17–22 25–30 mg/dm^3. Introduction acidification of raw sludge allowed to increase the stability of the aeration tanks and provide the following quality indicators of treated wastewater [19].

A new way is carrying out the process of acidification in the first anaerobic zone. If there is no mixing of the sludge mixture a compacted layer of sludge will be formed, it is followed by pre-fermentation retained on the sludge organic matter. Mean while the anaerobic zone continues to perform it's main function that is associated with the release of phosphate due to consumption of volatile fatty acids by phosphorochloridite bacteria. The increase in the concentration of volatile fatty acids in sludge mixture in the anaerobic zone contributes to a more stable phosphate removal from treated sewage. Compared to carrying out the acidification in ponds this process is more economical, as there is no need of construction or reconstruction of additional tanks (settling tanks, prefermentaters) and the cost of mixing is saved [20].

With the purpose of intensification of the acidification process in anaerobic and anoxic zones planar download is set. When placing in the anaerobic zone on the load a biofilm of specific microbial cenoses grows, which contains predominantly anaerobic heterotrophic bacteria adapted to entering to the area of organic substances and ensuring their quick destruction. High resistance of attached microorganisms to adverse impacts associated with changes in the characteristics of incoming wastewater increases the stability of the process of acidification and reduces the risk of disruption of the process of biological dephosphatization.

The technique how to define the acidification potential of sewage and raw sludge has been suggested [21].

Flow chart with biocoagulator. In accordance with this technology the first construction in the scheme is the biocoagulator where the raw wastewater contact with the circulating active sludge in the aeration conditions, after that the sludge mixture enters the primary sedimentation tank. Clarified effluent from the primary clarifier is sent to a denitrificator, and the flow of the activated sludge is treated first in an anaerobic bioreactor, and then also served in the denitrificator. Thus, in this scheme, anaerobic conditions required for biological phosphorus removal, are set up not in the sludge mixture but in the flow of activated sludge [22].

A significant gain in energy is obtained, if the bulk of the organic pollutants isolated from the wastewater before the aerobic purification, is sent to the digester and used for biogas production [14].

Embodiments of nitrification and denitrification. One of the directions of improvement of technological schemes for the removal of nitrogen and phosphorus is the system of step-by-step feed of wastewater for denitrification, which does not require recirculation, it means that the installation of additional pumps or stirrers also isn't required. Under this system, the wastewater is served in two or more reactors having a mixing zone and zone of aeration. Sludge and part of the waste water enter the mixing zone, and then to the aeration zone of the first reactor. To the mixing zone of the second reactor the sludge mixture from the aeration zone of the first reactor and the second part of wastewater is served. From this zone the sludge mixture is directed to the aeration zone of the second reactor. Depending on the established mode zones of mixing may be anoxic or anaerobic. The removal efficiency of nitrogen and phosphorus depends on the stability of mode mixing.

Apart from providing effective removal of nitrogen and phosphorus the attention is focused on the minimization of energy consumption in the implementation of new technologies. From the two corridors of aerotank carousel area is designed for the occurrence of nitrification and denitrification. The use of carousel reduces the number of mixers needed to maintain activated sludge in suspension and reduces energy costs.

Nitrification and denitrification can be implemented in the same volume of floating sludge. It simplifies the engineering design, but it is associated with a decrease of existing capacity by 25–30%. In addition, for the implementation of nitrification-denitrification in the same bioreactor strict regulation of dissolved oxygen concentration is required, i.e., special instrumentation and automation control is necessary [23].

The biomass concentration of activated sludge, application of immobilization. Implementing a collaborative process of combined biological removal of nitrogen and phosphorus requires more residence time of wastewater in biological treatment facilities, which leads to the need to increase their volume by 20–30%. In addition, because of the increasing of sludge index the number of secondary clarifiers should be increased. It makes necessary the development of technologies that ensure the efficiency of wastewater treatment from biogenic elements without increasing the size of the facilities, in particular by increasing the dose of activated sludge.

By breeding the dose of sludge 6,5–7,0 mg/dm^3 and the value of silt index 80–90 cm^3/g have been achieved, the sludge flakes had compact form, filamentous bacteria were virtually absent. Laboratory and industrial tests have shown high efficiency of removal of ammonium nitrogen and phosphate phosphorus with the use of high doses of activated sludge [24].

Acceptable one is a method of concentrating biomass by combination in the biological treatment reactor of the suspended and immobilized on inert carriers forms of microorganisms. Due to the significant increase in the concentration and age of the active biomass in the treatment system, as well as the creation of different oxygen conditions in the thickness of the attached biological film technology with the immobilization of the microbial biocenosis provides: the high oxidizing power of treatment and a significant decrease in their volume and resource consumption; the possibility of effective flow in the same volume both the processes of biodegradation of organic pollutants and nitrification-denitrification and biological removal of phosphorus compounds; improving the reliability and stability of biosystem activity and minimizing the sludge foaming [25–27].

As a method of enrichment of activated sludge with nitrifying bacteria it is suggested to use the reactor-bioaugmentator. The biomass of nitrifying bacteria increases when there a short aeration of the mixture of return activated sludge and wastewater sludge thickener is taken place [28].

Membrane methods. In the construction of new and reconstruction of existing treatment facilities a number of new solutions is suggested, technically the most affordable of which nowadays the membrane bioreactor (MBR) is meant to be. Using the MBR allows to increase the effectiveness and reliability of sewage treatment plants, increase their productivity, reduce occupied area, reduce the amount of excess activated sludge.

The main difference between membrane bioreactor and systems of traditional biological treatment in aerotanks is the presence of a membrane module, which is designed for the separation of sludge mixture and is an alternative to widely used method of the sedimentation of activated sludge in secondary sedimentation tanks [29].

Conclusion. The analytical review of modern methods of improving the biological wastewater treatment from nitrogen and phosphorus has been conducted. The focal areas of improvement are reducing of energy costs, reducing of the amount of construction while maintaining high removal efficiency of nitrogen and phosphorus.

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