Technology for biological treatment of urban wastewater and sludge treatment with deep removal of nitrogen and phosphorus

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Abstract. This article is dedicated to increasing of removing of nitrogen and phosphorus in DENIFO technology, and the removing of phosphorus by reagents. Removal of nitrogen and phosphorus from municipal wastewater prevents eutrophication of open water, which has become a global problem. A list of conditions that provide maximum efficiency of the processes of wastewater treatment and sludge treatment is completed. Functions of primary settlers, air tanks (based on technology DENIFO), and secondary settlers is reviewed. Pre-denitrification of the returned active sludge with the partial flow of waste water improves anaerobiosis in the anaerobic zone of biological block, and promotes intensive dephosphorization. The work was made under normal conditions of wastewater treatment plant. Unfavorable periods (snowmelt, torrential rains, floods) are not taken into consideration. Mathematical equations are made for the average flow of wastewater during dry weather. Combined dehydratation of the sludge and sediments (the long stay in the tank) leads to rapid displacement phosphorus phosphate to drain water, and a corresponded increase the content of phosphorus in the treated water. Also recommendations for changing the operating mode of the block of sludge treatment given. The important results included in article was taken on the really functioned wastewater treatment plants of Saint Petersburg. This work is aimed at a comprehensive assessment, development and improvement of technology of removing nitrogen and phosphorus from municipal wastewater, including from secondary pollution coming from the return flow from the sludge treatment units.

1. Introduction
The variety of technological and design solutions, especially clearly manifested in foreign practice, makes it possible to use a variety of scheme options depending on specific local conditions. In Russian practice, due to the mass use of standard projects, there is less variety of techniques for implementing this type of technology.

When reconstructing existing structures, the problems are reduced to the arrangement of anaerobic – anoxic compartments in two–, three– and four-corridor standard aeration tanks.

Limiting the task of reconstruction of structures and construction of new treatment plants to only Russia and the CIS countries, we will reduce the variety of possible options to a several denitrification and dephosphatisation schemes (Denifo). At the same time, we will make a list of conditions that ensure maximum efficiency of wastewater and precipitation treatment processes.

2. Clarification of waste water, fermentation of pollutions and sediments of primary settlers
The high effect of wastewater clarification in primary settlers means the removal of a fine-dispersed suspension, that approaches the properties of the colloidal dispersed phase, which is useful for
denitrification and dephosphatation processes. Therefore, the achievement of deep clarification, the use of pre-aeration, and the coagulation of wastewater in primary settlers are undesirable and sometimes even negative factors.

In case of highly diluted wastewater, primary settlers are included in the scheme of circulation of activated sludge: circulating activated sludge is partially or fully introduced in the primary clarifiers, the clarified liquid is sent to the aeration tanks, the settled sludge and suspended matter are also pumped there, with the sedimentary part of the settlers plays the role of anaerobic – anoxic zones, i.e. becomes pre-denitrifier.

The bioblock is performed according to the scheme of Anaerobic-Anoxic-Oxide wastewater treatment (scheme AA/O). The introduction of the reagent into the primary settling tanks destabilizes colloidal and part of the dissolved contaminants, and as a result of their removal, the amount of denitrified nitrogen decreases [3,4].

Another way to infuse wastewater with the products of fermentation of pollutants is to accumulate and ferment the sediment directly in the primary settlers. The sediment layer increases by 5-10 cm per day in the settlers, and the accumulation of sediment up to 1-1.5 m high lasts 3-4 weeks.

At the same time, external signs of fermentation are expressed as an intense gas release, floating of sediment particles up to the water surface, darkening of water due to the formation of iron sulfides. Despite the apparent discomfort in the appearance of settlers, there is a deeper denitrification in the bioblock taking place (a decrease in the amount of nitrogen nitrates by 2-4 mg/l).

The accumulation of sediment in the settlers produces a dense and viscous layer on the bottom, which leads to necessary weekly unloading of this layer for dehydrating. For a sake of better sediment fermentation control, it is advisable to switch one of the primary settlers to the fermenter mode.

All sediment from other settlers is discharged daily into the fermenter, which is supplied with a smaller amount of water (30-50% of the normal rate) in order to wash out the fermentation products in the bioblock. The amount of sediment from primary settlers is reduced, the increase in active sludge and the removal of phosphorus from the system grows. The sediment dehydrating unit must be prepared for such mode of operation.

Next, the composition of clarified water is determined by the decrease in the concentration of pollutants with sediment (by its ash-free part). Thus, the goals and objectives of wastewater clarification include the processes of water preparation for denitrification and dephosphatation, which significantly changes the operation regulations of this node [2].

3. Technological schemes and bioblock modes.

Effective reagent-free removal of phosphorus and nitrogen is achieved in cleaning schemes that include pre-denitrification of circulating active sludge and a maneuverable section for anoxic – oxide treatment of the sludge mixture (a section with agitators and aerators).

The scheme shown on figure 1 has two versions: with a sludge denitrifier in the head of the bioblock and inside the anoxic zone.

In the first case (figure 1A), the circulating activated sludge is returned to the head compartments in fractions \( R_1 \) and \( R_2 \). If the concentration of nitrogen/nitrites in the sludge is low enough (4-4.5 mg/l), then all the sludge is fed to the anoxic zone (pre-denitrifier), into which part of the wastewater is admitted (flow \( q_1 \)). The high content of nitrogen nitrates in the sludge (7-8 mg/l) makes it necessary to feed it in fractions: as a stream to the main denitrifier \( R_1 \) and to the pre-denitrifier \( R_2 \), depending on the presence of easily oxidized organic matter in the wastewater.

The maneuverable compartment can serve as a continuation of the denitrifier or the beginning of the oxide part, for example, when the water temperature decreases during snowmelt. The advantages of the scheme are the ability to control the operation of the predenitrifier by manipulating the \( q_1 \) and \( R_2 \).

In the second case (figure 1B), denitrification in the activated sludge is done in the main denitrifier. Creating the most favorable conditions for the operation of the anaerobic zone is achieved by regulating the flow \( R_2 \), but the dose of sludge in the anaerobic zone can be reduced to the minimum acceptable level (1.2-1.5 g/l), which is undesirable. The maneuvering section performs the same functions.
Both schemes are fundamental for Denifo processes that are used in the conditions of the traditional composition of urban wastewater COD 300-400 mg/l, total nitrogen up to 40 mg/l and the required quality of purified ode in the range of 10-12 mg/l for total nitrogen and 1-1.5 mg/l for total phosphorus.

When the requirements for the quality of treated water are decreased, the schemes are simplified: the maneuvering zone is removed, the flow control $q_1$ and $q_2$, $R_i1$ and $R_i2$ is eliminated, and finally the AA/O scheme with fixed volumes of ANA and ANO compartments remains (Figure 2).

The addition of reagents to reduce the concentration of phosphorus to 0.5 mg/l changes the situation somewhat. There is no need for careful preparation of the circulating sludge before the anaerobic zone; the issues of regulating the concentration of phosphorus in the treated water are solved by changing the dose of the reagent.

In the AA/O scheme (Figure 2) the reagent can be introduced before secondary settlers or in circulating activated sludge.

When feeding the coagulant before the secondary settlers, in order to meet the required quality of treated water, it is necessary to: set a variable dose of the reagent in accordance with the hydrograph and pollutograph of the water mass and contamination; take into account changes in pH and water alkalinity; adjust the processes of formation of FePO4 and Fe(OH)3 over time and in the volume of the flocculation zone in the secondary settling tanks.
When the coagulant is fed into the circulating activated sludge, the reagent dose is set constant (or proportional to the sludge flow rate when regulating recirculation), and all fluctuations in parameters must be compensated by the accumulating capacity of the activated sludge [3]. Of course, there may be some overspending of the reagent due to overdose to compensate the natural fluctuations in the biological purification process. Reagent dose according to Fe⁺³ 1.5-2.0 g / m³ when feeding into sludge, 3.0-4.0 g / m³ when feeding before secondary settlers [3,4].

4. Secondary settlers
The role of secondary settlers is significantly enhanced due to restrictions on the removal of phosphorus with active sludge. For example, with an increased phosphorus content in sludge, the removal of phosphorus by 0.36-0.45 mg / l, there will be an increase in the total phosphorus concentration by 0.36-0.45 mg / l, which will significantly reduce the overall efficiency of wastewater treatment. Therefore, it is necessary to achieve the maximum possible effect of treated water clarification in secondary settlers.

Ways to drastically reduce the amount of suspended matter in treated water are associated with new processes – coagulation and flocculation of treated water, ultrafiltration using bactericidal membranes, or simple filtration on granular mineral and plastic filters.

Simple sedimentation of the sludge mixture reduces the concentration of suspended substances to 7-8 mg / l, and this level can be considered the limit. The load on 1 m² of the settlers bottom area is reduced to 0.8-1.0 m³ / m² * h [4].

The outflow of activated sludge particles is facilitated by the unsuccessful design of sedimentation tanks in general and sludge pumps. In typical radial settlers, the small size of the inlet chamber creates powerful flows of the sludge mixture, so that the forming sludge flakes are cast away to the periphery. The identical size of sludge pumps and one collecting pipe do not provide even removal of sludge.

It is advisable to increase the intake chamber and set the duration of the sludge mixture presence in it for 25-30 minutes, replace the sludge pumps with scrapers, and organize the removal of circulating sludge from the central pit (except for settlers with a diameter of 54 m). The recommended changes take into account the possibility of reagents introducing before secondary settlers, when the inlet device becomes a flocculation chamber.

Among the various methods of intensifying clarification, the simplest is the coagulation of the sludge mixture with mineral reagents, combined with the removal of phosphorus, the addition of flocculants, or the use of a mixture of mineral and organic polyelectrolytes (composite mixtures of flocculants with mineral coagulants). The introduction of reagents into the circulating sludge improves the ability of the sludge to sediment.

5. Sediment treatment
Stabilization of sediment in aerobic or anaerobic conditions produces secondary pollutants in the form of ammonium nitrogen, nitrates and orthophosphates, and the inclusion of such processes in the precipitation treatment scheme is undesirable. Decaying organic matter of sediment is necessary for denitrification and dephosphatisation. For these reasons it is recommended that the dehydration of raw sediment and their subsequent stabilization and disinfection by composting or elimination by burning.

The main tendency in the preparation of sediment for dehydration is separated preparation of the sediment from primary settlers and excess activated sludge. Mixing of sediment and sludge causes active displacement of phosphates from the bacterial cells, sometimes in huge quantities (250-280 mg / l of phosphorus).

The technology of sediment and sludge compaction is changed in order to reduce the compaction time to 8-10 hours, with the addition of 1-1.2 kg of flocculant per 1 ton of dry matter [1].

Separate compaction of the sediment of primary settlers is useful from the point of decrease of water-yielding properties during its fermentation. In the sludge-compactor, it is necessary to provide rod agitators for separating gases and breaking down the layered structure of sediment.
Separately compacted sediments are dehydrated on centrifuges (centripresses), or on band filter presses. In the first case, the flocculant dose is 4-5 kg / t for sediment and 5-6 kg / t for excess sludge [5]. Sediment is fed to the belt filter presses through vortex flocculation chambers, into which flocculants with a dose of 3-4 kg/t are introduced [1].

Increasing the productivity of the dehydrating unit is achieved by installing drum, band or disc plate thickeners. It is possible to apply a mixture of sludge and sediment onto thickeners, and then thicken it to a humidity of 93-94% when dosing 1.8-2.2 kg/t of flocculant [1,4].

Dehydrating of sediment can be accompanied by a large removal of phosphates with fugate or filtrate. It is advisable to remove phosphates by introducing coagulants based on iron Fe+3. The coagulant is dosed directly into the flow of fugate (filtrate), which is then sent to the head of the treatment facilities.

The burning of dried enough sediment, as is customary at St. Petersburg water treatment plants, creates a number of restrictions, including achieving a sediment moisture content of no more than 75%, and an ash content of no more than 40%.

6. Conclusion
The main result of this article is revealing of the peculiarities of the water treatment plant as a single system focused on the removal of urban wastewater and return flows of nitrogen and phosphorus, as well as the choice of a rational, efficient and reliable integrated technological schemes of biological and chemical-biological (nonchemical and chemical) wastewater and sediment treatment.

References
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