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OPTIMAL RATIO OF PRIMARY AND SECONDARY CLARIFIER CHARACTERISTICS IN WASTEWATER TREATMENT PLANTS

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Abstract: *The issues of optimization of aerobic biological wastewater treatment processes are considered. Optimal ratios of characteristics and sizes of primary and secondary sedimentation tanks, as well as their relationship with the concentration of activated sludge by volume, are revealed. Graphical representations of the dependence of the volumes of primary, secondary and total volumes of structures on the concentration of activated sludge in cleaning processes with low and high loads are obtained. Experimental studies have shown that the concentration of activated sludge in the aeration tank and the silt index directly affect the deposition characteristics of activated sludge, in particular the hydraulic surface load (upward flow velocity).*
Keywords: *activated sludge, aeration tank, wastewater, concentration, sludge dose, secondary sedimentation tank, measurement accuracy, rectangular tank, radial tank.*

Аннотация: *Оқава сувларни аэроб биологик тозалаш жараёнини оптималлаштириш масалалари кўриб чиқилган. Бу ерда биринчи ва иккинчи тиндиргичларнинг ўзаро оптимал тавсифлари ва ўлчамлари ҳамда уларнинг фаол лойқа концентрацияси билан ҳажм бўйича боғлиқлик нисбатлари аниқланган. Тозалаш жараёнида фаол лойқа концентрациясининг паст ва юқори юкламаларда, биринчи ва иккинчи ҳамда умумий тиндиргич ҳажмларининг ўзаро боғлиқлиги график кўринишда олинган. Фаол лойқанинг концентрацияси ва лойқа индекси фаол лойқанинг тиниш тавсифига ва кўпгина ҳолларда, гидравлик юзали юкламага бевосита таъсир қилиши тажриба йўли билан тадқиқ этилган.*
Таянч сўзлар: *фаол лойқа, аэротенк, оқава сув, концентрация, лойқа дозаси, иккиламчи тиндиргич, ўлчаш аниқлиги, горизонтал тиндиргич, радиал тиндиргич.*

Аннотация: *Рассмотрены вопросы оптимизации процессов аэробной биологической очистки сточных вод. Вявлены оптимальные соотношения характеристик и размеров первичного и вторичного отстойников, а также их взаимосвязи с концентрацией активного ила по объему. Получены графические представления зависимости объемов первичных, вторичных и общих объемов конструкций от концентрации активного ила в процессах очистки с низкими и высокими нагрузками. Экспериментальными исследованиями доказано, что концентрация активного ила в аэротенке и индекс ила напрямую влияют на характеристики осаждения активного ила, в частности на гидравлическую поверхностную нагрузку (скорость восходящего потока).*
Ключевые слова: *активный ил, аэротенк, сточные воды, концентрация, доза ила, вторичный отстойник, точность измерения, горизонтальный отстойник, радиальный отстойник.*

Introduction

The most important problem of obtaining maximum cleaning efficiency is to ensure the optimal coordination of the characteristics of aeration tanks and secondary sedimentation tanks. The characteristics of activated sludge in the aeration tank, the main of which are its concentration and sludge index, have a direct impact on the structural and technological parameters of the secondary sump. Another factor that directly affects the operation of the secondary sump is the degree of saturation of the air supplied to the inlet of the sump: the increased air content of the drain initiates subsequent degassing of the stream, causing the sediment to rise and carry out with clarified water. The high concentration of nitrates ($N\text{-}NO_3$) in the water-sludge mixture supplied to the sedimentation contributes to the development of denitrification processes, as a result of which the settled and compacted mass of activated sludge decomposes and part of the microbial mass is removed with the treated effluent. At the same time, the parameters of recycled activated sludge into the aeration tank directly affect the characteristics of the aeration tank, and first of all, its oxidative power, which determines the degree of biological wastewater treatment.

The secondary sedimentation tank implements the processes of separation of suspended solids, concentration and compaction of the microbial mass, and its retention in the structure with an increase in hydraulic load. Thus, the functioning parameters of the main elements of the technological scheme of the treatment system (aeration tank and secondary sedimentation tank) are closely interconnected and the quality of wastewater treatment as a whole depends on their coordination.

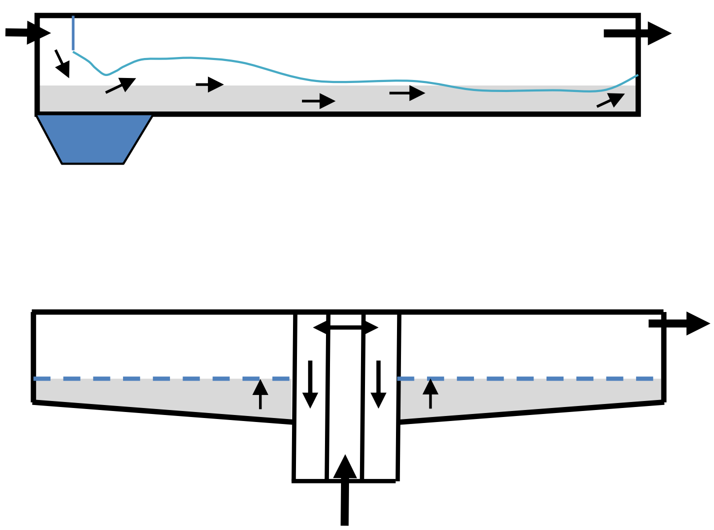
Materials and methods

During the present work, two configurations of secondary sedimentation tanks were tested, differing in the method of supplying and settling the drain:

➢ rectangular sedimentation tanks with a water-silt mixture supply device at the end of the structure and a length/depth ratio of 6, while the width of the structure remained constant in length, which favored the formation of a stable horizontal flow;

➢ radial sedimentation tanks with a water-sludge mixture in the central part and a radius/depth ratio of 5, providing the ability to filter the mixture through a settled (fluidized) bed of activated sludge.

The hydraulic flows of wastewater and activated sludge in the above types of sedimentation tanks are shown in figure 1.



a

b

Figure 1. ***Schematic flows in a rectangular (a) and radial (b) secondary sedimentation tanks.***

The concentration of activated sludge in the aeration tank and the sludge index directly affect the precipitation characteristics of activated sludge, in particular, the hydraulic surface load (upward flow rate) [1].

For horizontal m of rational sedimentation tanks, the curves of the limiting hydraulic load (upstream velocity) are given depending on the generalizing parameter - the reduced volumetric coefficient of the sedimentation tank K_v equal to the product of the sludge index and the concentration of sludge in the sludge supplied to the sedimentation. The approximation of the obtained experimental data made it possible to derive empirical dependences for determining the maximum hydraulic load (upstream velocity) on the settlers of various types:

- for horizontal sump

$$qc \lim_{i} l_h = 2{,}56 \cdot e^{-0{,}002K_v} \quad (1)$$

- for radial sump

$$qc \lim_{i} l_h = 1{,}25 \cdot e^{-0{,}003K_v} \quad (2)$$

where: q – wastewater flow; c – activated sludge concentration; l_h – hydraulic load.

The given empirical dependencies can be used:

- For optimal coordination of operation modes of aeration tanks-secondary sedimentation tanks during the design of aerobic biological treatment facilities;
- To predict the performance of secondary sumps according to the parameters of activated sludge in the aeration tank during operation of existing treatment facilities.

In the table. 1. shows the effect of the concentration and silt index of activated sludge in the aeration tank on the maximum hydraulic load (upward flow velocity) in the secondary sump.

Table 1.

The effect of the concentration and silt index of activated sludge

The concentration of activated sludge in aeration tank, g/l	**Silt index ml/g**	**The given volumetric coefficient of the sump, ml/l**	**Maximum hydraulic load, $m^3/m^2 \cdot h$**
3,0	150	450	1,05
4,5		675	0,6
6,0		900	0,4

It is seen that a decrease in the concentration of activated sludge in the aeration tank allows the sump to function with a maximum hydraulic load (upward flow rate) and thus avoid loss (removal) of activated sludge with clarified water.

The dependence of the silt index (ml/g) on the type of wastewater treatment in the aeration tank is given in table 2.

Table 2.

The dependence of the silt index (ml/g) on the type of wastewater treatment in the aeration tank

Carbon				**Nitrogen**	**Phosphorus**	
Extended aeration	Low load	Average load	High load	Nitrification / Denitrification	Physicochemical treatment	Combined processing
150		100	70	150	110	

An important characteristic of the functioning of sedimentation tanks is also the required depth of the zone of accumulation of biomass of activated sludge, the size of which determines the available volumetric capacity of the facilities. According to the results of the work, this design parameter of the sump is also associated with the parameters of the aeration tank and can be calculated according to the following empirical dependence [1]:

$$h = \Delta C \cdot V_{BA} \cdot \frac{I}{1000 \cdot S} \quad (3)$$

where *ΔC* is the decrease in the concentration of activated sludge in the aeration tank (from the concentration in the recycled sludge); V_{BA} - is the volume of the aeration tank; *I* - silt index of activated sludge in aeration tank; *S* - is the surface of sedimentation.

The V_{BA}/S ratio for treatment facilities with prolonged aeration was about 10, therefore, the depth of the zone of accumulation of biomass of activated sludge in the sump at a sludge index of 1 = 150 *ml/g* under the test conditions was about 1.5 *m*.

The large depth of the sediment accumulation zone allows the accumulation of activated sludge at times of high hydraulic loads, the duration of which affects the size of the sedimentation surface. With an increase in hydraulic loads, there is a decrease in the concentration of activated sludge in the aeration tank and an increase in the ascending velocity in the sump, which allows to reduce the volume of the sump (Fig. 2, 3).

The concentration of activated sludge in the aeration tank and the sludge index, and hence the sedimentation parameters, are greatly influenced by the degree of activated sludge recirculation into the aeration tank. An increased degree of recirculation leads to low concentrations of return sludge, and this does not allow to raise the level of sludge concentration in the aeration tank more than a certain maximum value.

The maximum possible concentration of recycled activated sludge is inversely related to the sludge index and is determined by empirical relationships:

at $I < 200$ *ml/g* $Cr_{max} = 1000/I$

at $I > 200$ *ml/g* $Cr_{max} = 1200/I$

The degree of recirculation determines not only the concentration of activated sludge and the sludge index in the aeration tank, but also the residence time of activated sludge in the secondary sump. Therefore, the degree of recirculation must also be limited in order to avoid swelling, anaerobnosis or denitrification, i.e. disruption of the functioning of the secondary sump due to the emergence of large fragments of compacted masses of activated sludge. In the case when the concentration of nitrates (N - NO_3) is more than 8 *mg/l* at the exit of the aeration tank, the denitrification process in the mass of settled activated sludge is not produced and sediment removal with clarified water does not occur.

The value of the degree of recirculation realized in practice depends on the season: about 150% in the dry period and 100% in the rainy period.

With hydrodynamic equilibrium of the system, the degree of recirculation (t) is determined by the thickening factor (f_{tf}) which is an indicator of the quality of activated sludge:

$$f_{tf} = 1 + \frac{1}{t} \quad (4)$$

where the f_{tf} = 2 at t = 1.0 (100% recirculation), f_{tf} = 1.67 at t = 1.5 (150% recirculation).

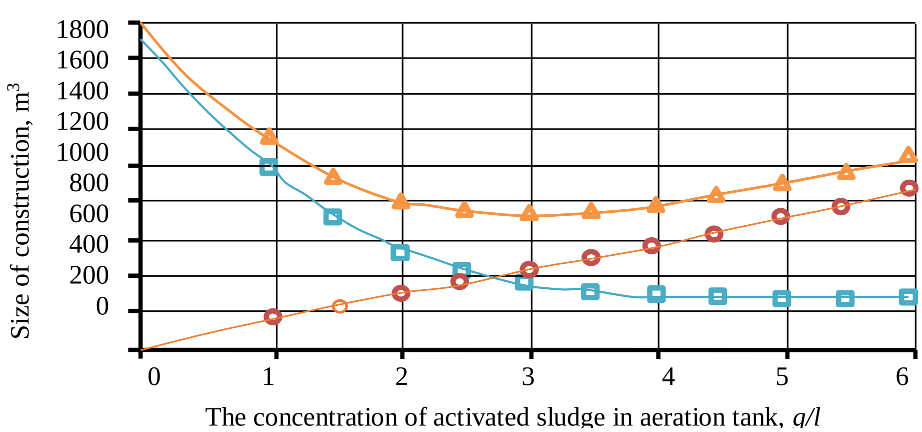


Fig. 2. ***Volumes of aeration tank and secondary sump and total volume of structures (aeration tank + secondary sump) in high-load processes:***

Aerotank: $V_{BA} = -14{,}468a_i^2 + 203{,}33a_i^2 - 963{,}81a_i^2 + 1756{,}1$, $R^2=0{,}99$; *Secondary sedimentation tank:* $V_C = 122{,}18a_i + 24{,}182$, $R^2=0{,}99$; *Aerotank + second sedimentation tank:* $V_m = -13{,}271a_i^3 + 194{,}97a_i^2 - 832{,}35a_i + 1788{,}5$, $R^2=0{,}98$.

There is also a very definite relationship between the degree of recirculation and the depth of the settling zone: the lack of volume for accumulation of activated sludge leads to the need for intensive recirculation, which allows us to direct the sludge from the aeration tank in a circle. However, with a high degree of recirculation, there is a risk of degradation of the quality of activated sludge.

The parameters characterizing the state of activated sludge in the aeration tank (sludge concentration and sludge index) depend on the size of the secondary sump. The concentration of activated sludge at the inlet to the sludge tank mainly depends on the volume of the aeration tank and the load on pollution of ha activated sludge. An increase in the concentration of activated sludge in the aeration tank at any load certainly leads to a decrease in its volume. The required volume of the secondary sump in this case increases, but to a different extent:

- intensively - at high loads;
- weak - at low loads.

As a result, the required total volume of structures (aeration tank + sump) depending on the concentration of activated sludge in the aeration tank varies differently:

- at high loads, the total volume has a minimum value at a sludge concentration of about 3 *g/l*;
- at low loads, the total volume continuously decreases as the sludge concentration increases (up to the tested concentrations of 6 *g/l*).

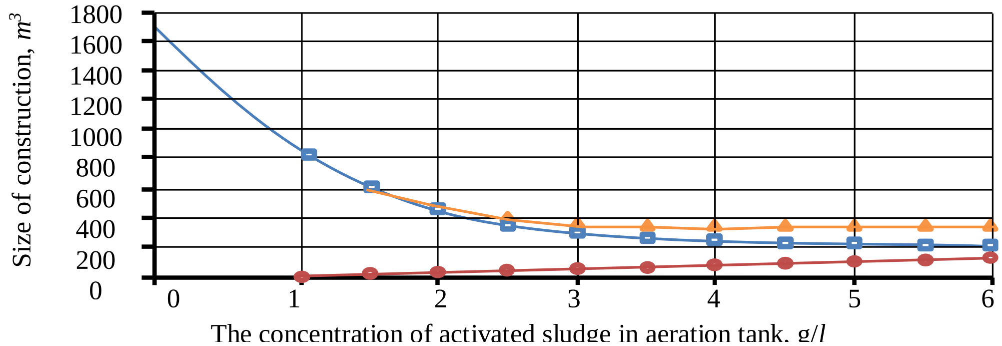


Fig. 3. ***Volumes of aeration tank and secondary sump and total volume of structures (aeration tank + secondary sump) in high-load processes:***

△ *Aerotank:* $V_{BA} = 13.395ai^3 + 189.84a_i^2 – 910.96a_i + 1699.7.1$, $R^2 = 0.99$; □ *Secondary sedimentation tank:* $V_C = 123a_i$; ○ *Aerotank + second sump:* $V_T = -13.451a_i^3 + 190.38a_i^2 - 890.49a_i + 1689.9$, $R^2 = 0.99$.

According to the test results, the maximum concentration of activated sludge in aeration tanks that implement various technological modes had the following values:

- with prolonged aeration - 4.5 *g/l*
- at low load - 4.0 *g/l*;
- at an average load of 3.0 *g/l;*
- at high load - 2.0 *g/l*.

Conclusion

Based on the results of this work, it can be recommended that the following measures to achieve optimal coordination, ensuring the highest possible degree of wastewater treatment for a given layout of treatment facilities:

➢ selection of the type of aeration tank and its structural and technological parameters that provide optimal ratios of filamentous and zoogley microorganisms in the biocenosis of activated sludge;

- Preliminary hydromechanical treatment of activated sludge biomass used for bioflocculation of dispersed colloidal suspensions of incoming wastewater;
- Regulation of hydraulic and air flow regimes, providing an optimal distribution of oxygen transfer rates, dissolved oxygen concentrations and oxygen consumption by active biomass;
- Controlling the pollution load on activated sludge and increasing the oxidation power of the aeration tank due to the optimal regulation of the supply of recycled activated sludge;
- Ensuring optimal design dimensions and the required residence time of the water-sludge mixture in the secondary settling tanks;
- Introduction to the technological scheme of a stabilizing pool for buffering and parrying the amplitude-frequency fluctuations of the load at the entrance to the aeration structure.

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