Improving the Efficiency of Sewage Treatment Plants on the Example of Treatment Plants in the Cities of Artem and Vladivostok

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Abstract. Fugate water, when it enters the beginning of sewage treatment plants (STP), increases the load on the biological treatment system. Methods of purification of the STP return water are considered. A new composite composition has been developed for the reagent precipitation of ammonium and phosphates from water, which is formed as a result of thickening and dewatering of sludge. On the basis of the experimental data obtained, a technological scheme for the treatment of water formed after mechanical dewatering of excess activated sludge and sludge from the operation of treatment plants at biological wastewater treatment plants has been developed. The developed technological solution makes it possible to exclude the effect of aluminum on activated sludge and minimize the negative effect of ammonium and phosphates, with minimal construction and operating costs. The proposed cleaning method is applicable to both existing treatment facilities and newly designed ones.

1. Introduction

Recycled waste water at treatment facilities is saturated with ammonium and phosphates [1]. A large amount of ammonium in wastewater adversely affects the flora and fauna of water bodies; when wastewater is returned to the n of structures with a maximum amount of biogenic elements, the load on the operation of bioreactors increases [2]. Currently, one of the requirements for urban wastewater treatment technologies is the need to remove nitrogen, phosphorus and organic compounds in order to reduce the load on wastewater treatment plants.

The most intensive input of nutrients into wastewater occurs during their sedimentation, when sludge water from dehydration of sediments returns to the "head" (beginning) of structures [3].

At urban wastewater treatment plants built in the last century, cleaning schemes prevail: grate crushers, sand traps, primary sedimentation tanks, aeration tanks, secondary sedimentation tanks, contact tanks for chlorine disinfection. Modern biological treatment systems are represented by structures of periodic action and flow type, with free floating biomass and attached microflora. Treatment regimens include aerobic, anaerobic, anoxic and combination zones. Regardless of the nutrient removal method chosen, excess biomass is generated in the system, which is usually first compacted and then dewatered before incineration or sedimentation. This produces sludge water (fugate) with a high content of ammonium and phosphates [4], which are returned to the distribution chamber in front of the primary settling tanks (the beginning of the structure). Unlike nitrogen, which
in biological wastewater treatment systems is removed in gaseous form during denitrification, phosphorus is removed in excess sludge. Moreover, the biomass accumulates the maximum amount of phosphorus at the end of the aerobic zone of the aeration tank in the form of polyphosphates [5]. When processing excess activated sludge under anaerobic conditions, polyphosphates are decomposed and released into water [6], therefore, prior to mechanical dewatering of sediments, it is preferable to use a scheme of gravity compaction of sediments without installations for anaerobic digestion. Phosphates and ammonium are removed from wastewater by biological, physicochemical and combined methods [1]. Purification of circulating water by biological methods is time-consuming [7] and requires specially adapted biomass [8], since the quantitative proportion of nutrients 100BOD:5P:1N a balanced composition of microorganisms is formed.

Typically, aluminum and iron salts are used for the reactive precipitation of phosphates. Recently, unconventional coagulants have begun to be used, for example, polytitanium chloride [9] and composite compositions. The article [10] investigates the effectiveness of the developed alkaline composition for wastewater with a low pH environment (less than 6.5). Composite reagents include mixtures of coagulants in various proportions and have been used for a long time, and the use of coagulating-flocculating compositions is becoming increasingly important for wastewater with a certain composition. The increased concentration of nutrients in wastewater entering the treatment plant leads to an increase in the load on the structures, so that the existing structures cannot cope with the removal of organic compounds [11].

The application of technology for biological removal of ammonium and phosphates has another feature. It consists in the fact that microorganisms that accumulate phosphorus, under anaerobic conditions, release the accumulated phosphorus in dissolved form into water. Excess sludge is subjected to gravity compaction for several hours before dewatering. This time is enough for all the phosphorus accumulated in it in the form of polyphosphates to go into a dissolved state in the sludge water. Therefore, when designing, it is necessary to take this feature into account and include in the technological chain the structures of chemical precipitation of ammonium and phosphorus in the form of insoluble precipitates. There is a way to treat waste water with reagents [12]. A method for purifying wastewater from ammonium ions includes adjusting the pH of wastewater using a reagent followed by treatment of wastewater with an oxidizing agent in an equivalent amount or with an excess of 5% relative to the amount of ammonium ions. In this method, wastewater is treated with technical magnesium oxide [13], the process is carried out in two stages in such a way that magnesium oxide is supplied to the second stage of wastewater treatment in excess, and magnesium oxide sludge from wastewater. from the second stage it is divided into two streams. The analysis of the considered methods of removing ammonium nitrogen showed that the most optimal is the reagent method, treatment with solutions of magnesium chloride and trisodium phosphate, where no preliminary wastewater treatment is required [14], the method of reagent treatment with aluminosilicate reagents was investigated [15]. Reagents such as aluminum chloride, polyoxychloride aluminum, polyaluminium sulfates, chlorosulfates are widely used all over the world and have long proven their effectiveness [16-17].

The purpose of the work is to identify the most effective methods for reducing the negative impact of ammonium and phosphates of return water from sewage sludge and secondary sedimentation tanks in biological treatment systems. As part of the reconstruction of sewage treatment facilities, a comprehensive scheme for removing ammonium and phosphates into sludge from circulating waters, with minimal investment and operating costs.

Experiment:
The studies were carried out as part of the development of a technological scheme for the reconstruction of treatment facilities in the city of Artem (Knevichi settlement) on the centrifugal water formed during mechanical thickening and dewatering of sludge on centrifugal decanters UCF 466-00-34 (Vladivostok Sewage Treatment Plants (STP) is Centralnye) Figure 1.
Figure 1. Diagram of biological sewage treatment facilities.

"Central" Vladivostok.

1 - grate building, 2 - aerated sand trap, 3 - sand trap, 4 - blowing station,
5 - aerotank nitrifier-denitrifier carousel type, 6 - horizontal secondary clarifier, 7 - sludge dewatering
building, 7.1 - centrifugal decanters for thickening and dewatering sludge, 7.2 - intermediate tank, 7.3
- screw pumps, 7.3 - flocculant preparation station,
8 - clarifier, 9 - reagent facility building, 9.1 - metering pumps, 9.2 - intermediate capacity of
compacted sludge,
9.3 - screw pumps, 9.4 - sludge moisture sensor, 9.5 - horizontal centrifuges,
9.6 - bulk water tank, 9.7 - coagulating column, 10 - sand filters, 11 - ultraviolet disinfection unit, 12
- excess sludge pumping station, 13 - reagent sludge pumping station.

Using a trial coagulation. After sedimentation of the solutions, a sample was carried out from the
middle of the clarified layer. The concentration of ammonium and phosphates is determined according
to the methods recommended in the specialized literature: ammonium - with Nessler's reagent,
phosphates - with a mixed reagent, residual aluminum - with aluminum. The research results are
presented in Figures 2-3 and Table 1.
Figure 2. Reagent treatment of fugate water.
1 - treatment with iron sulfate; 2 - treatment with iron sulfate and sodium hydroxide;
3 - processing Aqua-aurat⁴⁰.

Figure 3. Treatment of fugate water with aluminum sulfate and sodium hydroxide.
Table 1. Experimental data. Determination of the optimal coagulant.

| Substance | Initial sample, mg/l | Fugate water, mg/l | pH solution after treatment | Time, min | Colour | The effect cleaning, % |
|-----------|----------------------|--------------------|-----------------------------|-----------|--------|------------------------|
| FeSO₄ 5%  | 192,74               | 4                  | 7                           | yellow    | 0      |
| PO₄       | 0,03                 |                    |                             |           | 98     |
| NH₄       | 62,82                | 69,00              | 5                           | 7         | yellow-green | 0 |
| PO₄       | 0,21                 |                    |                             |           | green  | 98 |
| Al(OH)₃Cl₃H₂O 5% (13 ml) (aqua aurat³⁰) | 8,55            | 5,5            | 7                           | clear     | 86     |
| PO₄       | 0,33                 |                    |                             |           | 99     |
| NH₄       | 62,82                | 20                 | 6                           | 7         | gray   | 68 |
| PO₄       | 0,71                 |                    |                             |           | 98     |

2. Experiment results

The efficiency of purification with coagulant FeSO₄ was 98% for phosphates, and for ammonium, an increase in concentration in the purified water was observed. Ferrous sulfate is a fairly effective coagulant for use as additional purification of wastewater from phosphates, since the payment for the negative impact on the environment with residual iron in 2021 is 5950.8 rubles per ton, but there are also negative aspects of this reagent, any wastewater contains ammonium compounds, when the ammonium compounds react with iron sulfate, ammonia hydrate is released (formula 1-2), which confirms the increase in the ammonium concentration in the experiment.

\[
\begin{align*}
\text{Fe}_2\,(\text{SO}_4)_3 + 12\text{NH}_3 & \rightarrow [\text{Fe}\,(\text{NH}_3)_6]_2\,(\text{SO}_4)_3 \quad (1) \\
\text{FeSO}_4 + 2(\text{NH}_3\cdot\text{H}_2\text{O}) & \rightarrow \text{Fe(OH)}_3 + (\text{NH}_3)_2\text{SO}_4 \quad \uparrow (2)
\end{align*}
\]

When the wastewater is purified with iron sulfate after alkalization, the same chemical reaction occurs with the release of ammonia hydrate, since pH in this case does not affect the course of the reaction.

Table 1 shows that the efficiency when using Aqua-aurat³⁰ is 86% for ammonium and 99% for phosphates, with a high degree of additional purification from nutrients, but there are also opposite sides, a low pH value of 5.5 and aluminum ions remain in the water after additional purification ...

Based on the Federal Law N7 [18] Article 16, a fee is charged for negative impact on the environment for discharges of pollutants into water bodies, at the rates of fees for 2021 for aluminum, the fee is 18 388.3 rubles per ton.

Aluminum sulfate, when used together with sodium hydroxide for alkalization, purifies water by 68% in terms of ammonium and 98% in terms of phosphates. Residual aluminum is present in the sample (Figure 3).
Residual compounds in the form of metals. Complete coagulation of aluminum salts with the formation of insoluble precipitates occurs at an excess alkalinity of 1-2 mol / l. Figure 4 and Table 2 show the results of reagent treatment of concentrated water with excess alkalinity with Aqua-Aurat\textsuperscript{30} coagulant.

**Figure 4.** Reagent treatment of Aqua-Aurat\textsuperscript{30} with excess alkalinity.

**Table 2.** Results of treatment of Aqua-Aurat\textsuperscript{30} fugeate water with excess alkalinity.

| Substance | Initial sample, fugeate water, mg/l | After treatment, fugeate water, mg/l | pH | Time, min | Colour | Residual aluminium, mg/l | The effect cleaning, % |
|-----------|----------------------------------|-----------------------------------|----|----------|-------|------------------------|-----------------------|
| NH\textsubscript{4} | 62.82 | 7.12 | 6.5 | 7 | clear | 0.03 | 90 |
| PO\textsubscript{4} | 29.81 | 0.28 | | | | | |

The cleaning efficiency with coagulant Aqua-Aurat\textsuperscript{30} was 99% for phosphates and 90% for ammonium. Residual aluminum is within the normal range for fishery reservoirs.

To reduce the operating costs of mineral coagulants, a new composite composition for reagent precipitation of phosphates from concentrated water has been developed, which has a high coagulating ability due to metal ions in seawater; more than 1 g/m\textsuperscript{3}.
Table 3. Results of treatment of centrate water with aluminum sulfate with seawater.

| Substance | Initial sample, mg/l | After treatment, fugeate water, mg/l | pH solution after treatment | Time, min | Colour | Residual aluminium, mg/l | The effect cleaning, % |
|-----------|----------------------|--------------------------------------|-----------------------------|-----------|--------|--------------------------|-----------------------|
| NH₄       | 62,82                | 3,21                                 | 6,8                         | 7         | clear  | 0,00                     | 98                    |
| PO₄       | 29,81                | 0,17                                 |                             |           |        |                          | 99                    |

According to the results presented in Table 3, it can be seen that the maximum efficiency of wastewater treatment has been achieved, which is 98-99% in relation to ammonium and phosphates, the pH corresponds to the norm, this reagent is required less for additional wastewater treatment (Figure 5).

Figure 5. Reagent treatment with aluminum sulfate and sodium hydroxide and sea water.

In order for the coagulation process to continue, it is necessary to provide optimal conditions for mixing waste water with reagents and for the maturation of flocculants (flocculation process). For the purification of centrifugal water, the design of the coagulating column has been developed (Fig. 1, p. 9.3). The slurry water treatment unit includes: an intermediate pumping station 9.2, three units for pumping and dosing reagents with back pressure, dosing pumps (9.1), a coagulating column (9.3). The residence time of waste water in the column is seven minutes.

The project for the reconstruction of the 9th block provides for separate dewatering of sludge containing reagents and removal of solid waste to the landfill to fill the space between the briquettes of pressed waste. The sludge, which does not contain aluminum salts, can be used to fertilize the soil.

Analyzing the experience of operation of treatment facilities in Vladivostok, as part of the development of a project for the reconstruction of treatment facilities in the city of Artem, a complex technological solution for the removal of phosphorus and nitrogen was developed (Figure 6).

The STP was put into operation in 1978. The structure of the structures includes: a building of gratings, horizontal sand traps with a circular movement of water, primary sedimentation tanks displacing aeration tanks, secondary sedimentation tanks, a contact tank, a chlorination station, and a
blower. Treatment facilities are represented by sludge platforms on an artificial foundation and a sludge pumping station. Drainage water from the sludge pads is returned to the head of the structures into the distribution chamber of the primary clarifiers. Capacitive reinforced concrete structures (sedimentation tanks, aeration tanks) have been preserved in a fairly good condition, but the technology for cleaning and processing the sludge does not meet modern environmental requirements.

Reconstruction includes:

- replacement of technological equipment of the building of the gratings;
- installation of modern equipment for sand removal and dewatering;
- replacement of the aeration system of the aeration tank (installation of disc aerators, distribution channels and replacement of perforated pipes with a tubular fine-bubble aeration system);
- construction of an installation for preparation and dosing of reagents for wastewater post-treatment and re-equipment of a contact tank into a reagent wastewater treatment settler;
- construction of an ultraviolet disinfection unit;
- construction of sludge dewatering.

![Figure 6. Scheme of reconstruction of treatment facilities in Artem.](image)

1 - grate, 1.1 - sand trap, 2 - sand trap, 3 - primary settling tank, 4 - displacing aeration tank, 5 - secondary settling tank, 6 - reagent housing body, 6.1 - dosing pumps, 6.2 - waste water mixer with reagents, 7 - contact tank, reconstructed into a sump with thin-layer modules, 7.1 - flocculation chamber, 8 - installation for ultraviolet disinfection, 9 - installation for thickening and mechanical dewatering of sludge, 9.1 - batch-type gravitational installation. sludge compactors, 9.2 - intermediate tank of compacted sludge, 9.3 - screw pumps, 9.4 - sludge moisture sensor, 9.5 - horizontal centrifuges, 9.6 - hydrocyclone, 9.7 - centrifugal water tank, 9.8 - coagulating column, 9.9 - metering pumps, 9.10 - flocculant preparation station, 9.11 - dispenser for sludge disinfection reagents; 10 - blowdown station, 11 - reagent sludge pumping station, 12 - excess sludge pumping station, 13 - pumping station for mixing excess sludge and primary sludge, 14 - reserve sludge platforms.

The phased withdrawal of phosphates and ammonium in the technological scheme is provided at three points:
- in the form of polyphosphates with excess sludge at the end of the aeration zone of the aeration tank;
- in the form of an insoluble sediment during post-treatment with reagents;
- when treating fugate water with coagulants.

Removal of ammonium and phosphates from the system of biological treatment facilities is carried out with dewatered sludge.

3. Conclusion
1. The developed technological solution allows to minimize the negative impact on the activated sludge of circulating waste water with a high content of ammonium and phosphates with minimal construction and operating costs. The proposed cleaning method is applicable to both existing treatment facilities and newly designed ones.
2. The most effective reagents for purification of centrifugal water are: Aqua-aurat30, but for the discharge of wastewater into reservoirs, it is necessary to take into account the neutrality of the pH of the aquatic environment and the compound reagent aluminum sulfate, and sea water.
3. Studies have shown that it is not recommended to use ferrous sulfate in wastewater treatment, since the interaction of ammonium compounds with ferrous sulfate releases ammonia hydrate, which causes an unpleasant odor during the reaction.
4. It was found that after coagulation the reagents Aqua-aurat30 with sodium hydroxide and aluminum sulfate with sodium hydroxide, as well as sea water, showed themselves well; this water can be returned to the beginning of the structures.

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