The study of the use of "Dezolak" for disinfection and deodorization of sewage sludge

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Abstract. Experimental studies on the decontamination and stabilization of sludge were carried out using the product "Desolak", which is calcium oxide treated with a disinfectant. As a result of the research, it was found that the sewage sludge of Voronezh is safe and can be used as organic fertilizer for growing agricultural plants. The determination of the content of mineral nutrients in the soil and the soil reaction showed that the application of organic fertilizers in the form of sludge in comparison to the variant without fertilizers increases the content of nitrogen nitrate, exchange potassium, and mobile phosphorus in the soil. At the same time, the mass fraction of impurities of toxic elements in the soil decreases when sewage sludge is added as an organic-lime fertilizer.

1. Introduction
More than a hundred million tons of organic sediment is stored at water and utility enterprises in Russia, excluding waste from livestock farms. Major of sewage sludge is delivered to sludge dewatering sites. Currently, most silt sites are overflown and are often located in residential areas of cities.

Organic sediments belong to the fourth or fifth hazard class, therefore, the problem of their disposal is relevant from an environmental, economic and social point of view. According to Dovgan S.A. “The task of utilizing sludge from sewage treatment plants in Voronezh is generally one of the main environmental problems (exhaustion of the capacity of sludge maps, odor effects) [1].

Sediment of urban wastewater is a valuable organic mineral product used for growing agricultural products in various countries of the world. This is due to the fact that the solid phase of sediment contains more than 50% of organic substances, as well as complexes of nitrogen, phosphorus and potassium. Organic and mineral substances increase the yield of cultivated plants when they are brought to the soil [2]. The use of sediment is constrained by the possibility of the presence of pathogenic microorganisms and heavy metals, which is unacceptable when applied to the soil. “The correct use of sediment will increase soil fertility and crop yields, and protect the environment [3]."

The safety of sewage sludge according to sanitary and hygienic indicators is determined by the presence of pathogenic microorganisms and helminths’ eggs. Disinfection of sewage sludge can be carried out by adding lime to it, which is common in Europe and the USA. “The method of disinfecting sewage sludge with quicklime is used at individual treatment facilities in Finland, Germany, Sweden, the USA and other countries” [4].
Safety in terms of sanitary and hygienic indicators of sewage sludge is assessed by the presence and viability of pathogenic microorganisms and helminth parasites’ eggs. Liming can significantly reduce the content of pathogenic microorganisms that is a potential hazard. Of the existing reagents, lime is most widely used due to its low cost. When quicklime is added, alkalinity increases, due to the process of extinguishing lime by the water contained in the sediment, the temperature of the sediment increases. According to the studies of Ignatenko A., when a dose of lime is administered up to 30% by dry matter of the sediment, deformation and death of fecal streptococci, Salmonella bacteria occurs. As the pH rises above 11, the content of coliform bacteria decreases from 10⁹ to 10³ pcs. per 1 g of dry matter [5, 6].

As a result of studies conducted by various authors [2, 5, 6], it was determined that the treatment of dehydrated sewage sludge with quicklime (CaO) has a longer effect. With a lower water content in the sediment, it is more resistant to the development of acid fermentation processes. When using quicklime, depending on the content of free water (20-30%) and the initial temperature of the sludge, the dosage should be from 100 to 150 kg of CaO per ton of sludge or from 400 to 500 g of CaO for every kilogram of free water to reach a temperature above 50 °C [7, 8].

Mixing sewage sludge on a twin-screw mixer with quicklime with an activity of 55-58% containing 6-25% CaO by weight of sludge is shown in Fig. 1. Adding lime in an amount of 23.5% allows to increase the temperature of the mixture to 78-82 °C for 10 minutes, then the temperature drops to 46 °C, within 40 minutes [5, 9].

The required dose of quicklime is determined from the condition of increasing the temperature of the sediment more than 60 °C and depends on the composition of the sediment and processing methods. The process of extinguishing lime occurs according to the following equation:

\[
\text{CaO} + \text{H}_2\text{O} = \text{Ca(OH)}_2 + 65\text{kJ.}\]

(1)

Consequently, when extinguishing 1 kg of chemically pure lime containing 100% CaO, 1152 kJ of heat is released, with 320 g of water required.

The amount of heat needed to heat the sediment with quicklime can be determined by (2) [2, 5, 7]:

\[
Q_T = (M_{\text{sed}} \cdot C_{\text{sed}} + M_{\text{lim}} \cdot C_{\text{lim}}) \Delta T,
\]

(2)

where \(M_{\text{sed}}\) and \(M_{\text{lim}}\) are the sediment and lime mass, kg; \(C_{\text{lim}}=0.92\) – specific heat of lime, kJ/(kg °C); \(\Delta T\) – temperature difference required for heating the precipitate and the initial, °C.

The specific heat of the sediment is determined by the formula:

\[
C_{\text{sed}} = 1.8(1 + 0.85 \cdot W_{\text{sed}})
\]

(3)

where 1.8 is the heat capacity of dry sediment with a moisture content of 5-10%, kJ/(kg °C); \(W_{\text{sed}}\) – sediment moisture, fractions of a unit.

The amount of heat obtained by slaking lime, taking into account its CaO activity, will be:

\[
Q_T = 1152 \cdot A \cdot M_{\text{lim}},
\]

(4)

where A is lime activity, fractions of a unit.

From the equation of material balance, you can preliminarily determine how much the temperature can increase when a certain dose of lime is added to the sediment:

\[
\Delta T = \frac{1152 \cdot A \cdot M_{\text{lim}}}{M_{\text{sed}} \cdot C_{\text{sed}} + M_{\text{lim}} \cdot C_{\text{lim}}}.
\]

(5)

By setting the required temperature, it is possible to determine the required mass of lime for sludge:
Based on the conditions of complete quenching of active lime in the sewage sludge, it is theoretically possible to determine the sludge moisture:

$$W_c = \frac{1000 \cdot W_{sed} - 0.32 \cdot A \cdot M_{lim}}{M_{sed} + M_{lim}}. \quad (7)$$

where $W_c$ – humidity of the precipitate obtained after adding lime to it, a fraction of units.

The above formulas (2-7) can be used for approximate calculations, which is due to the heterogeneity of lime by size and quality of particles, the presence of bound moisture in sediments with various forms of solid particles. As a result of this, the calculated dependences require some adjustment. Since the consumption of lime significantly depends on humidity, it is advisable to carry out preliminary thickening or dewatering of sediments.

The content of heavy metals in the sewage sludge depends on the enterprises discharging water to the treatment plant. For each city such indicators will differ. The MPC (maximum permissible concentrations) of heavy metals in sewage sludge is strictly regulated. Table 1 shows the MPC values for different countries and Russia according to regulatory data.

| TM | Germany | Finland | Austria | France | Sweden | Holland | Switzerland | EEC Directives | Russia |
|----|---------|---------|---------|--------|--------|---------|-------------|----------------|--------|
| Pb | 1200    | 1200    | 500     | 300    | 300    | 500     | 900-1500    | 750            | 1000   |
| Cd | 20      | 30      | 10      | 15     | 15     | 10      | 25-40       | 20             | 30     |
| Cr | 1200    | 1000    | 500     | 200    | 1000   | 500     | 900-1500    | 750            | 1200   |
| Cu | 1200    | 3000    | 500     | 1500   | 3000   | 500     | 900-1500    | 1000          | 1500   |
| Ni | 200     | 500     | 200     | -      | -      | 100     | 150-300     | 300            | 400    |
| Hg | 25      | 25      | 10      | 8      | 8      | 10      | 8-15        | 16             | 15     |
| Zn | 3000    | 5000    | 2000    | 3000   | 10000  | -       | 2500-4000   | 2500          | 4000   |
| Mn | -       | 3000    | -       | 500    | -      | -       | -           | -              | 2000   |
| Co | -       | 100     | 100     | 200    | -      | -       | 80-150      | -              | -      |
| Ag | -       | -       | 100     | -      | -      | -       | -           | -              | -      |
| As | -       | -       | -       | -      | -      | -       | -           | -              | 20     |

Analyzing this table, we can conclude that the Russian standards comply with generally accepted international standards. In terms of arsenic content, they are higher than in the above countries.

2. Experimental part

Experimental studies on the disinfection and stabilization of sludge sediments were carried out using the product “Desolac”, which is calcium oxide treated with an ovicidal substance. “Dezolak” products are manufactured by Pridonkhimstroy Lime LLC in accordance with TU 21.23.25-004-00112170-2016. “Desolak” is intended for disinfection and stabilization of sewage sludge, sewage from livestock and poultry enterprises for the purpose of their further use in agriculture, industrial floriculture, landscaping and landscaping of settlements, for biological reclamation of disturbed lands, solid waste and solid waste landfills, as well as restoration of soil fertility in agriculture and forestry.
The disinfecting reagent is SE-1 (ROSUN). It is produced in the form of a white or gray powder with a moisture content of 0.5%, a bulk density of at least 0.9 g/cm$^3$, and solubility in water up to 20 g/l. It is a strong oxidizing agent that provides, in addition to exposure to pollutants, a disinfecting effect. The composition of the drug includes the following substances:

- potassium monopersulfate (double salt up to 18-24%),
- sodium chloride (1-5%),
- active oxygen (7-9%).

There is a passport on the reagent, which reflects 17 items required for the corresponding document in the Russian Federation. According to the safety data sheet, the product undergoes biological oxidation and does not accumulate biologically. The disinfecting effect of the drug is also provided by its pronounced oxidizing ability. The mechanism of the bactericidal effect is reached by blocking the transmission of ribonucleic acid and destroying the genetic system. When dissolved in water, active oxygen, a hydroxyl free radical, hydrogen peroxide and hypochlorous acid are formed. All components act simultaneously on organic substances of technogenic and natural origin and inorganic substances with variable valency.

Depending on the percentage of disinfecting reagent, the product is divided into:

- "Desolak - B" calcium oxide with an additive in an amount not exceeding 2% by weight;
- "Desolak - F" calcium oxide with an additive in an amount not exceeding 1.5% by weight.

The main indicators are presented in table. 2.

The difference between these products is the percentage of disinfecting additives, which is associated with the quality of disinfecting sediments:

- “Desolak-B” is intended for disinfection, stabilization and deodorization of sewage sludge from municipal wastewater treatment plants (a mixture of domestic, industrial and storm sewage), and can also be used at local treatment facilities of various industrial enterprises in combination with other treatment technologies.
- “Desolak-F”, in addition to the application for the previously listed sediments, can be used for disinfection, stabilization and deodorization of effluents of livestock and poultry complexes.

**Table 2. Key indicators of the quality of the product "Desolac".**

| Quality indicators                  | "Desolak - B"       | "Desolak - F"       |
|-------------------------------------|----------------------|----------------------|
| Active CaO                          | not less than 80%    | not less than 80%    |
| Temperature of the reaction with water | 70-85 °C             | 70-85 °C             |
| Reaction Time                       | 3-15 min.            | 3-15 min.            |
| Disinfecting additives             | not more than 2%     | not more than 1.5%   |
| Fractional composition of grains    | not more than 200 microns | not more than 200 microns |
| Bulk density                        | not less than 700 kg/m$^3$ | not less than 700 kg/m$^3$ |

“Desolak” is made of pure carbonate rocks that have undergone thermal heating at a temperature of 900 to 1100 C to produce calcium oxide. Next, grinding to 200 microns occurs. It is mixed with disinfecting additives in an amount of 1.5-2.0%.

For the use of this product there is a Certificate of Conformity ROSS RU. ПИЩ01.Г111108№ 2210018 "Passport of compliance of chemical products". For the disinfecting reagent there is an “Expert Opinion No. 6/2-P dated 02/12/2015” and a Quality Certificate ISO 9001: 2008. It is a product of the second hazard class according to GN 2.2.5.1313-03 and GOST 12.1.007.

Studies on the addition of a disinfectant were carried out at the treatment facilities of Voronezh. The sludge was processed in a plant (Fig. 1), consisting of a Desolak feed hopper (point 2), a sludge screw mixer with lime (point 3). The precipitate was pre-dehydrated on filter presses. Quicklime from the silo through the auger is fed to the screw mixer, where lime is mixed and dosed with sludge (Fig. 2). The treated sludge is discharged in an automated mode. The experimental setup is shown in Fig. 3.
Figure 1. The scheme for the treatment of dehydrated sludge with the Desolak product:
1 - dehydrated sludge; 2 - lime supply; 3 - screw lime sludge mixer; 4 - discharge of treated sludge.

To determine the content of toxic elements in the treated sludge, experimental studies were carried out at the Left-bank treatment facilities of Voronezh (LLC "LOS"). The crude sludge from the primary sumps and were mixed with quicklime and dehydrated on a Flottweg decanter (Fig. 2).

Figure 3. Obtaining processed sludge:
a) Flottweg Decanter Centrifuge; b) sludge discharge; c) type of precipitate obtained

3 Evaluation of the results
When conducting experiments on the decontamination of sewage sludge, problems arose in the reaction of lime. Completely dehydrated sludge does not fully react, and the desired decontamination effect is not achieved. Based on the experiments, the required water content in the sediment was set. The experiments were carried out with crude sludge and a mixture of crude sludge and excess activated sludge. To obtain generalized research results in various proportions were mixed: sediment, excess activated sludge and the product “Desolak”, the data on the samples are presented in table. 3.

Table 3. Sludge samples from wastewater treatment plants.

| Sample | Sample Content |          |          |
|--------|----------------|----------|----------|
|        | crude sediment, % | excess activated sludge, % | Desolac, % |
| №1    | 100            | -        | 5        |
The best option for adding the treated sediment into the soil is sample No. 3. To determine the amount of heavy metals in the sediment and soil, when applying it, an experiment was conducted for two samples with and without "Desolak".

The amount of added sediment was determined by the formula (8), taking into account the content of heavy metals in the soil and sediment:

$$D_{tm} = \frac{(0.8 \times PDC - F) \times 3000}{C_{tm}}, \tag{8}$$

where:
- $D_{tm}$ - theoretically permissible sediment rate, t / ha dry weight;
- $PDC$ - maximum permissible concentration of heavy metal in the soil, mc / kg;
- $F$ - actual heavy metal content in soil, mg / kg;
- $C_{tm}$ - the content of heavy metal in the sediment, mg / kg dry weight;
- 3000 - mass of arable soil layer in terms of dry matter, t / ha.

For dehydrated sludge (30% crude sludge, 70% excess activated sludge) of treatment facilities treated with “Desolak” in the amount of 5%, the application dose calculated for 60 kg of active substance per hectare based on nitrogen content was 3.78 t / ha.

For dehydrated sludge (30% crude sludge, 70% excess activated sludge) of treatment facilities, the application dose calculated for 60 kg of active substance per hectare based on nitrogen content was 4.45 t / ha.

The sediment was put under the main tillage.

Studies conducted at treatment facilities have shown that in the sediment after treated with “Desolak” product, the mass fraction of toxic element impurities is not significant. The determination of heavy metals in samples was carried out at the Voronezh State Center for Agrochemical Service. The mass fraction of heavy metal impurities in the dehydrated sludge treated with “Desolak” product and the standard content are shown in Table 4.

**Table 4. Physical and chemical indicators of sewage sludge**

| Name of indicator          | Regulatory requirements for sewage sludge | Permissible total impurity content of heavy metals in mg/kg of dry matter | Value of indicator | Sludge | Sludge with Desolac |
|----------------------------|------------------------------------------|----------------------------------------------------------------------------|-------------------|--------|---------------------|
|                            |                                          | I category of soil | II category of soil |                  |        |                    |
|                            |                                          | 1 | 2 | 3 | 4 | 5 | 6 |
| Moisture content, %        | <<82                                     | 70 | 70 |                  | 36.4 | 63.6 |
| pH                        | 5.5-8.5                                  | 6.0-8.0 | 6.0-8.0 |                  | 6.4 | 12.2 |
| Mass fraction of organic matter per dry matter, % | 40-60 | >30 | >30 |                  | 72.9 | 66.1 |
| Mass fraction of nitrogen, % | 1-3 | >0.6 | >0.6 |                  | 1.84 | 2.6 |
| $P_2O_5$, %                | 1-4                                     | >0.7 | >0.7 |                  | 1.14 | 1.4 |
| $K_2O$, %                  | 0.2-0.7                                  | >0.1 | >0.1 |                  | 0.1 | 0.13 |
| Hg, mg/kg                  | 15                                      | <2.1 | <7.5 |                  | 0.45 | 0.41 |
| Cr, mg/kg | <1200 | <80 | <200 | 48.3  | 20.7  |
|-----------|-------|-----|------|-------|-------|
| Pb, mg/kg | <1000 | <130| <250 | 114.9 | 97.1  |
| Ni, mg/kg | <400  | <132| <750 | 27.2  | 20.4  |
| As, mg/kg | <20   | <2  | <10  | 0.5   | 0.6   |

Specific activity of technogenic radionuclides (ACs/45*ASr/30), dry matter

| Mass concentration of pesticide residues in dry matter, mg / kg |
|---------------------------------------------------------------|
| - HCH (total isomers)                                         |
| - DDT and its metabolites (total amount)                      |
| <0.1                                                          | <0.007 | <0.005 |
| <0.1                                                          | <0.005 | <0.005 |

The presence of viable eggs and larvae of helminths, including nematodes (ascaridate, trichocephalus, strongylates, strongyloids), trematodes, cestodes

| Tsisty of intestinal pathogenic protozoa                       |
|---------------------------------------------------------------|
| not allowed                                                  | not detected | not detected |

The presence of larvae and pupae of synanthropic flies

| not allowed                                                  | not detected | not detected |

The use of lime-stabilized sludge on agricultural land is constrained by the presence of toxic elements and parasitological parameters in sewage sludge. However, the experiments and the results of the analyzes show that the use of such a sedimnt is safe.

As can be seen from the table, 4 (column 5, 6) in the treated sludge, the mass fraction of heavy metal impurities is much lower than the normative ones. For example, for group I sediment, nickel contains 0.07-0.1 MPC, chromium 0.04 MPC, lead 0.2-0.45 MPC, mercury 0.01-0.06 MPC, arsenic 0.05-0.07 MPC, cadmium 0.09-0.17 MPC. The MPC of the mass fraction of toxic element impurities for group II sediments is twice as large as group I. Sediment of group I refers to fertilizers of group I, and can be used:

- Fertilizers of group I: fertilizers based on sewage sludge used for growing industrial, fodder, grain and green manure crops in a personal subsidiary farm for growing seedlings of vegetable and flower crops;
- Fertilizers of group II: fertilizers based on sewage sludge used for planting forestry crops along roads, in nurseries of forest and ornamental crops, floriculture, for cultivating depleted soils, reclamation of disturbed lands and slopes of roads, and reclamation of solid household waste dumps.

Accordingly, the resulting sediment can be applied to the reclamation fields with a frequency of no more than 2-3 years, in the amount of 5-15 t/ha in terms of dry matter, according to formula (8).

When conducting studies to determine the effectiveness of the use of sewage sludge in conjunction with the Scientific Research Institute of Agriculture of the Central Black Earth Strip named after V.V. Dokuchaev [2, 9, 10] obtained results proving the effectiveness of winter rape cultivation Adriana for
increasing the green mass of plants. The concentration of substances necessary to improve soil fertility increases when the sediment is treated with lime [2, 9, 10]. A decrease in the content of heavy metals in the treated sludge was noted, compared with the initial concentration in the sludge of sewage inlet.

One of the main factors influencing the applied treated sediment on soil fertility is the content of minerals in the soil and the reaction of the soil environment. In the soil, when conducting research, there was an increase in the content of metabolic potassium by 3.5 mg / 100 g abs. dry soil or 18.6%. The increase in the content of mobile phosphorus varied: with the addition of dehydrated sludge, it increased by 4.5 mg / 100 g abs. dry soil or 7.6%, and with the introduction of sludge sediment treated with the drug “Desolak” practically remained at the control level. An increase in the content of nitrate nitrogen in the soil with silt sediment by 0.8 mg / kg abs. dry soil or 11.9%, with “Desolac” 1.5 mg/kg abs. dry soil or by 22.4%. The results are shown in table 5.

Table 5. The content of mineral nutrients and the reaction of the soil in the soil layer of 0-20 cm when applying sludge

| Option                              | Indicator | N-NO₃* | P₂O₅** | K₂O** | pH CO₂l |
|-------------------------------------|-----------|--------|--------|-------|--------|
| The control                         |           | 6.7    | 59.5   | 18.8  | 7.24   |
| Silt sediment treated with “Desolac”|           | 8.2    | 57.0   | 22.3  | 7.35   |
| Silt sediment                       |           | 7.5    | 64.0   | 22.3  | 7.27   |

Note: * mg / kg of soil
** mg / 100 g of soil according to Chirikov

Accounting for the yield of green mass of winter rape and statistical processing of the results showed that the introduction of sludge from sewage treatment plants under the main tillage increases the productivity of winter rape. Excessive yield of green mass of winter rape when applied:
- silt sewage sludge treated with “Desolak” - 7.87 t / ha or 20.1% more than the control option;
- silt sludge - 9.56 t / ha or 24.4% more than the control option.

The use of sludge from wastewater treated with “Dezolak” slightly changes the reaction of the soil medium in the direction of increasing the alkalinity of the soil solution by 0.11 pH units compared to the control variant, which is significantly less than the design and operation accepted in practice [8]. Thus, the use of sludge from sewage treated with “Desolac” will be more effective in soils with acidic reaction.

4 Conclusions
1. Wastewater sludge in Voronezh treated with the “Desolak” preparation is safe and, according to microbiological indicators, refers to clean soils in accordance with regulatory requirements.
2. In accordance with regulatory requirements, sludge from Voronezh sludge sites are safe in terms of the content of toxic elements significantly less than standard ones and can be used as organic fertilizers for use both in grain and industrial crops, and in vegetable growing.
3. As a result of the use of organic fertilizers - silt sediment treated with “Desolak”, pathogenic microflora, viable helminth eggs, cysts of pathogenic intestinal protozoa, enterococci and other dangerous biological agents are destroyed.
4. Dehydrated sludge treated with the product “Desolak” can be used in industrial floriculture, forest and decorative nurseries, for biological reclamation of disturbed lands and landfills. The introduction of such a precipitate increases soil fertility, due to an increase in the content of nitrogen, phosphorus and potassium in the soil, leads to an increase in the yield of winter rape by 20.1%. The use of sludge sediment as organic fertilizer does not affect the quality of cultivated plants. All indicators are within the maximum permissible concentration (MPC) or significantly lower.
5. The use of treated sediments of the city of Voronezh as organic-lime fertilizers for soils with pH less than 5.5 in doses calculated taking into account the calcium content in the composition of the
introduced sediment is recommended. When applying sediment as fertilizers, regional and local conditions should be taken into account, including soil properties and hydrological regime, normalized pollution, total and mineral nitrogen, phosphorus, potassium in sediment and soil, crop cultivation characteristics, and crop rotation.

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