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Use of the resource potential of soda production sludge

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Abstract. Soda sludge is characterized by a finely dispersed structure with a high pH value. These two characteristics of the sludge allow it to be effectively used as a material that inhibits vegetation growth. During operation, firebreaks can become overgrown with vegetation, which reduces their fire-fighting characteristics. The conducted analysis of the phytotoxicity formed by the sludge allowed us to establish the high efficiency of the proposed technology for the utilization of soda sludge. The technology does not require sludge preparation for use, which allows us to consider it as the best available technology.

Keywords: soda sludge, utilization, mineralized firebreaks, phytotoxicity, resource potential

Authors' contribution. *K.G. Pugin* — conceptualization, development of research methodology; *R.R. Salakhov* — data curation, writing — preparation of a draft manuscript, writing-reviewing and editing the manuscript. All authors have read and approved the final version of the manuscript.

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Использование ресурсного потенциала шлама содового производства

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Аннотация. Шлам содового производства характеризуется мелкодисперсной структурой с высоким значением pH. Эти две характеристики шлама позволяют его эффективно использовать в качестве материала, угнетающего рост растительности. При эксплуатации противопожарные полосы могут зарастать растительностью, что снижает их противопожарные характеристики. Проведенный анализ фитотоксичности, формируемый шламом, позволил установить высокую эффективность предложенной технологии утилизации шлама содового производства. Технология не требует подготовки шлама к использованию, что позволяет рассмотреть ее в качестве наилучшей доступной технологии.

Ключевые слова: утилизация, противопожарные минерализованные полосы, фитотоксичность, ресурсный потенциал

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Introduction

Surface water, groundwater, atmospheric air and soil are heavily influenced by anthropogenic activities in the chemical industry. Their impact is especially noticeable if the enterprise is located on the territory for several decades and its operation generates large-scale waste, for which there are insufficient technologies for their decontamination and recycling. The long-term placement of industrial wastes, even at low hazards for environment (ENV), leads to depletion of the ability of ENV to clean itself, which will lead to increased risks of man-made pollution. To reduce the negative impact of industrial enterprises on ENV facilities in the Russian Federation, several state programs and regulations have been adopted ("Environmental protection", "Circular economy", "About the national security strategy of the Russian Federation") aimed at creating conditions that would maximize the environmental impact with minimal economic costs. This is achieved through the scientific analysis of the mechanism for the technological transfer of industrial production to the ENV and the development of technologies for the utilization of previously generated and accumulated wastes, based on the principle of maximum use of their resource potential. In this paradigm, waste destruction technologies are not efficient because they do not involve the use of material resources of waste to create new socially demanded mothers, and the destruction itself requires energy costs. In most cases, low-environmental large-scale wastes can be used as feedstock based on their physical or chemical properties.

One of these large-scale wastes for which many recycling technologies have been developed, but which are not used because of the complexity of the process of disposal or because they require significant economic inputs, is sludge, from the production of soda ash.

In Russia, about 70% of the total volume of calcareous soda is produced by ammonia by two major producers JSC "Bashkiria soda company" (BSC) (located in the city of Sterlitamak, the republic of Bashkortostan) and JSC "Berezniki soda plant" (BSP) (located in the city of Berezniki, the Perm region). The BSC's slurry storage covers an area of about 460 hectares. The slurry storage of BSP is located on the bank of the Kama River, has an active map of 155 ha and a closed area of 89 ha, an estimated accumulated volume of slurries of about 20–21 million ton [1–3].

For the disposal of soda production sludge recycling technologies were previously developed that allow the use of soda production sludge to make building materials [4–8], sorbents [9–11], process raw materials to produce various materials [12–14] This technology implies the stage of preparation of sludge for further use, which requires considerable material and economic costs. The proposed technologies for producing targeted products and building materials presented in scientific publications did not always cover the full range of required characteristics. In particular, there are no studies on the resistance to frost, abrasion, durability, water-resistance, no questions of subsequent disposal of the product obtained from sludge after its use. The lack of such studies increases the risk of negative results in the implementation of the proposed recycling technology.

Analysis of previously published studies of physical-mechanical, chemical properties of soda production sludge allowed to determine a new direction of use of its resource potential. Sludge is characterized by high alkaline potential and fine-dispersed mineral structure, which allows to create an environment to prevent or significantly reduce the possibility of plant growth. It can be used to improve the operational characteristics of fire-resistant mineralized strips (FRMS) used to protect settlements, forests and industrial facilities from fires. During operation, FRMS are contaminated with grass and other vegetation, which impairs their fire-fighting functions [15]. According to GOST R 57972-2017, the main quality indicator of FRMS is their mineralization (absence of organic). In the case of a FRMS, to reduce the fertility of the top layer and create conditions for local suppression of plant growth, it is possible to use soda production sludge.

Methods and materials

In the study used sludge BSP obtained from closed and active slurry storage.

GOST 12536-2014 was used to evaluate the physico-mechanical properties of sludge. The granulometric composition was determined according to GOST 12536-2014. For the evaluation of the chemical characteristics of the distiller fluid (liquid phase sludge) methods were used according to SanPN 2.1.5.980-00; SanPN 2.1.4.1074-01.

The phytotoxicity of the mixture of soil and sludge was evaluated in accordance with MP 2.1.7.2297-07, FR.1.39.2006.02264 and GOST R 22030-2009 under ambient conditions. This method makes it possible to evaluate the suppressing or stimulating effect of a newly introduced component. The experiment was conducted using oat seeds. It was used as a clay loam that has a structure and composition characteristic for the soil cover of the Perm Region (Loamy eluvio-deluvial soil over brownish podzolic clay soil). For the experiment four compositions of soil/sludge were used: 1 version ratio — 0/1; 2 versions — 1/3; 3 versions — 1/2; 4 versions — concrete sample (soil without sludge). Based on the results of the measurement of the protruding roots, the effect of inhibition was calculated by the formula: $Ei = (Lc - Lex)/Lc \cdot 100$, where Ei — effect of inhibition, %; Lc — average root length in control, mm; Lex — average root length in experiment, mm. Phytotoxicity is considered proven if the calculation exceeds 20 %.

GOST P 57972-2017 was used to determine the conformity of the mineralized strips.

Results

Production of calcined soda by the ammonium process is controlled by the formation of a distillate liquid (pulp), which consists of solid (mineral) and liquid phase. During a long stay in the slurry reservoir under the action of gravity forces, the solid and liquid phases are separated. The solid phase settles on the bottom, and the liquid phase is thrown into the surface water object.

The liquid phase of pulp from the production cycle is characterized by a strong alkaline medium (up to pH = 12.4) and mineralization up to 180 10 g/ l. It contains a significant amount of dissolved ions — chlorides, sulfates, sodium and potassium, ammonium Table 1.

Table 1. **Chemical composition of the liquid phase of the waste pulp of the BSP, g/l**

Sample collection location	NH_4^+	Cl^-	Ca^{2+}	Na^++K^+	HCO_3^-, мг/л	SO_4^{2-}	Total mineralization	pH
Reset from the BSP	190±0.5	110±5	42±0.5	27±1	63±2	7.4±0.5	180±10	12.4
The part of the current sludge storage facility map opposite the discharge from the BSP	15.5±0.5	15±0.5	7±0.5	4.8±0.25	39±2	1.9±0.1	27±3	11.5

Source: compiled by K.G. Pugin, R.R. Salakhov.

The chemical composition of the dried sludge is a mixture of magnesium and calcium carbonates, as well as calcium sulphate.

Main chemical compounds in the mineral (solid) part of the sludge: $CaCO_3$ from 49 to 64 %; $MgCO_3$ from 19 to 26 %; $Ca(OH)_2$ from 3 to 11 %; SaC_{12} from 5 to 10 %; $SiO_2 + Al_2O_3$ from 4 to 11 %; $CaSO_4$ from 3 to 10 %; SiO_2 to 4.7 %. This indicates a high alkali resource potential of the sludge.

Two samples from the closed slurry storage map (samples 1 and 2) and the active map (samples 3 and 4) were used to determine the granulometric composition. The granulometric composition of the sludge is shown in Table 2.

Table 2. **Granulometric composition of sludge**

Sieve mesh size, mm	Sieve residue, % by weight			
	Sample 1	Sample 2	Sample 3	Sample 4
5	–	–	–	–
2	2.5	1.7	–	0.1
1	17.2	12.7	7.2	9.8
0.5	28	21.9	18.8	16.6
0.25	22.4	27.5	17.6	16.8
0.1	25.3	28.7	37.5	32.9
Passed through sieve 0.1	4.6	7.5	18.9	23.8

Source: compiled by K.G. Pugin, R.R. Salakhov.

The analysis of the granulometric composition of the mineral part of the sludge showed that in samples 1 and 2 there are particles of about 2 mm size, and the predominant particle size is from 1 to 0.1 mm. In samples 3 and 4, the predominant particle size is between 0.5 mm and less than 0.1 mm. With long-term presence of sludge in the slurry storage, fine particles are separated into larger ones. The results are corrected with the results obtained previously by C.M. Blinov et al. [4].

The results of phyto-toxicity studies on sludge have shown that it is useful to use sludge as a material to create conditions for local plant suppression. Previously obtained by E.V. Kalinina and L.V. Rudakova germination pea seeds, Figure 1, with different soil pH. In the first variant sludge was used as soil, in the second variant a mixture of sludge and soil, third (control) soil [16].

a *b* *c*

Figure 1. Results of the phytotoxicity experiment for different soil compositions:
a – pH – 12.8; *b* – pH – 8.6; *c* – pH – 7.0

Source: compiled by E.V. Kalinina [16].

The highest phytotoxic effect was 100% in the first option (Figure 1a). Germination of seeds took place but there was no growth. Visually, it can be determined that the high pH of the soil (added sludge) creates conditions for suppression of pea seed growth.

Additionally, we conducted a phytotoxicity study using oat seeds. The results of the contact phyto-testing carried out using mixtures with different soil/sludge combinations are presented in Table 3.

Table 3. **Phytotesting results**

Soil/sludge composition	Average root length, cm	Average sprout length, cm	Inhibition effect, %
0/1	0.7	0.9	83
1/3	1.7	2.3	59
1/2	2.8	3.4	33
1/0 (checking)	4.2	5.5	0

Source: compiled by K.G. Pugin, R.R. Salakhov.

The experiment confirmed that the use of soda production sludge can create conditions to significantly slow down the growth of plants until they stop growing and dying. At high pH, the soil calcium binds phosphorus compounds, making it inaccessible to plants, water balance is disrupted, and nutrients are poorly assimilated by plants.

According to the research of the Sukachev Institute of Forests about 60% of major natural fires occur precisely because of their rise and accumulation of combustible materials on their surfaces.

Depending on the working element used (by means of which the soil is developed), the cross section of the fire-resistant strip can be triangular, trapezoidal or straight-coal. The rectangular transverse shape of the FRMS is shown in Figure 2.

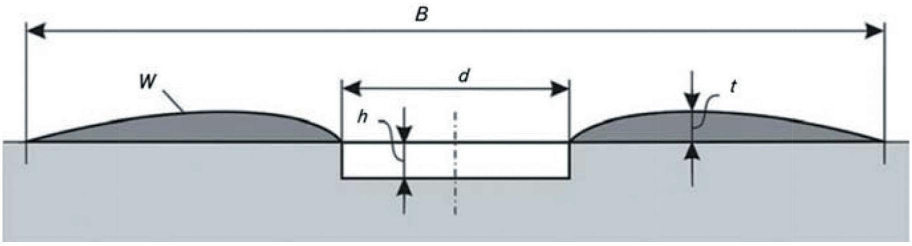

Figure 2. Rectangular cross-section of the PMP: *B* — strip width, *d* — excavation width, *h* — excavation depth, *W* — excavation soil, *t* — excavation soil layer thickness

Source: compiled by K.G. Pugin, R.R. Salakhov.

While creating FRMS, a d-wide recess is formed, which on the obverse side provides a mineral surface layer from which vegetation and the upper fertile layer are removed. The depth *h* is generally sufficient to prevent the spread of lateral sub-terrestrial grass shoots, but the depth *h* promotes the accumulation on its surface of organic matter (leaves, tails, etc.), which creates conditions for grass seed germination. Under these conditions, a rapid mineralization of the strip will occur with loss of fire-resistant properties.

To increase the effective operating time of the FRMS, it is recommended that the FRMS be removed by filling with sludge, which will prevent the accumulation of organic residues (leaves, tails, branches, etc.) on the strip.

The granulometric composition of sludge allows it to be introduced into the soil with a direct FRMS device and create a more dense structure of FRMS soil. Due to the fact that sludge is classified as class 5, it can be used in building technologies without restriction.

Impoundment of soda production sludge, which in its composition contains calcium carbonate, will form a high soil pH, which leads to the disturbance of the aboriginal structure of the soil characteristic for this area, and also forms an adverse chemical and physical action on soil microorganisms.

Conclusions

The soda production sludgh as a fine structure, with high pH can create at the chemical and physical level conditions reducing vegetation growth that can be used for FRMS device.

The time of effective use of FRMS can be increased by reducing nutrients in the surface layer of FRMS, increasing pH and structure density, which reduces the growth rate and spread of plants. It is proposed to prevent the accumulation of combustible organic materials on the surface of a FRMS by filling the mineralized strip with sludge at all depths. This technical solution will allow to maintain the fire-resistant properties of the undamaged strips for a longer period, effectively use the resource potential (high alkalinity and fine mine structure) of soda production sludge.

Sludge recycling technology meets environmental requirements and can be found to be efficient. It does not require advanced processing equipment and additional sludge processes.

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