The use of pulp and paper industry waste as soil for recultivation of disturbed lands

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Abstract. The article is devoted to the study of the use of waste from the pulp and paper industry as soil, which can be used in technical and biological recultivation of disturbed lands, industrial waste dumps and other applications in accordance with its purpose. Studies of soil obtained from frozen sediments of sludge-lignin of JSC "Baikal Pulp and Paper Mill (BPPM)" with the addition of waste activated sludge of sewage treatment facilities were carried out. They were aimed at the research of its chemical and agrochemical composition, as well as toxicological properties. The tests carried out showed that the obtained soil is capable of intensifying the recultivation succession of disturbed lands, and also contributes to an increase in the growth and biomass of plants and increases their ability to reproduce. Thus, the developed technology for processing sediments of storage cards of JSC "BPPM" is based on the creation of effective conditions for such natural processes as freezing, drainage, self-overgrowth and allows not only to reduce the technical and economic costs of waste disposal, but also to increase the social and environmental security of the region.

1. Introduction

In 2019, an anti-record for the industrial waste generation was set in Russia - about 8 billion tons, which is almost 4 times more than in 2002. Only 40% is subject to recycling, and the rest is disposed in landfill sites. Meanwhile, Federal Law No. 7 "On environmental protection" [1] clearly states that it is necessary to eliminate the accumulated harm to the environment, through work, including the disposal and recycling of accumulated waste of previous years.

The pulp and paper industry (PPI) makes a huge contribution to the mass of waste with an annual increase of up to 7 million tons, which has not yet been disposed. One of such striking examples is the huge amount of accumulated colloidal sediments of sludge-lignin (over 50 million cubic meters) at JSC "Baikalsky PPM", the city of Baikalsk; group "ILIM", the cities of Bratsk and Ust-Ilimsk of the Irkutsk region and JSC "Selenginsky pulp and paper mill" city of Selenginsk, Republic of Buryatia. But at present, the issue of the disposal of the accumulated waste of JSC BPPM, which is stored in storage cards located in the immediate vicinity of Lake Baikal and residential areas, is especially acute (figure 1).
Figure 1. Solzanskaya industrial site of JSC “Baikalsky PPM”; the volume of waste is more than 6.5 million cubic meters.

In connection with the current extremely critical socio-ecological situation, the Government Commission checked the implementation of the legislation on the conservation of lake Baikal and its environmental improvement. After that, on September 12, 2019 the President of the Russian Federation approved instructions that were to be implemented by January 1, 2020 [2], namely:

- to conduct competitive procedures aimed at selecting and implementing the world's best technological solutions for the waste management, including the participation of foreign companies with experience in this area;
- to approve a promising project for the development of territories of OJSC “Baikalsky PPM” which is undergoing bankruptcy proceedings.

However, despite this, the issue of waste disposal at OJSC “BPPM” has not been resolved in any way.

Guided by Federal Law No. 7 “On Environmental Protection” and the principles of the best available technologies in the field of waste processing, the most promising and environmentally safe direction for their disposal in this case is to consider the possibility of using natural processes with subsequent recultivation of disturbed lands. The advantage of the proposed technology [3] is a year-round seasonal implementation of engineering, reclamation and agrotechnical measures, which are aimed at intensifying the optimal conditions for the natural processes of drainage, freezing and recultivation succession of storage cards waste without the use of costly energy-intensive technologies.

2. Main part

From January 2019 to September 2020, FGBOU VO "IRNITU" and MUE "KOS BMO", Baikalsk, carried out pilot tests at the Solzanskaya industrial site of JSC "BPPM" to freeze the colloidal sediment of sludge-lignin and obtain valuable products from it - soil and fertilizers. The tests showed that freezing of colloidal sediments of sludge-lignin in storage cards under natural conditions is very effective. At the same time, the intensification of such sequential natural processes as drainage – freezing – recultivation succession makes it possible to improve the physicochemical parameters, reduce the volume, moisture and toxicity of precipitation [4].

It is known that one of the promising directions of biological recultivation of complex technogenic areas of disturbed lands is the creation of conditions for natural self-overgrowth, which is part of the recultivation succession [5]. Traditionally, succession means the sequential regular changing from one biological community (plants, animals, etc.) to another in a certain area of the environment in time as a result of the influence of natural or anthropogenic factors, while recultivation succession means natural or forced changes in vegetation on disturbed lands, landfills, industrial waste dumps, which lead to the restoration of disturbed lands. At the same time, the speed and intensity of recultivation
succession depends on the physicochemical, agrochemical indicators of disturbed lands or waste dumps. The studies carried out at a number of test sites have shown the effectiveness of successful natural overgrowth of technogenic lands. At the same time, the self-overgrowth of disturbed lands, landfills, waste dumps allows them to be left under natural overgrowing far from settlements, after a minimum amount of mining technical reclamation, which provides significant savings in labor and funds [6].

[7] describes pilot tests on the production of soil from colloidal sediments of sludge-lignin and other wastes of the Baikal region, such as ash from the TPP of JSC “BPPM”, waste activated sludge from the sewage treatment facilities in Baikalsk. The tests showed that to obtain soil as an additive, the best results are achieved with frozen lignin sludge and activated sludge from the Baikalsk sewage treatment facilities in a ratio of 4: 1, which was taken by us for further research. Heavy metals were chosen as the studied chemical indicators, which were determined by method [8], since they lead to one or another disturbance of phyto- and agrocenoses, and in certain cases even to complete degradation of plant communities. As agrochemical indicators, attention was paid to the content of the main nutrient elements for plants, such as organic matter [9], phosphorus and potassium [10], total nitrogen [11], as well as the hydrogen index of salt and water extracts [12,13], characterizing acidic properties of the soil. We analyzed the soil obtained in the pilot tests and the sludge - lignin frozen in natural conditions (table 1). All work was carried out in an accredited laboratory for environmental monitoring of natural and technogenic environment No. ROSS RU.0001.518897 FGBOU VO “IRNITU”.

**Table 1.** The content of metals and agrochemical composition of obtained soil and frozen sediment of sludge-lignin in 2019 and 2020.

| Parameters                        | Obtained soil | Frozen sludge-lignin | Norm according to state standard P 54534-2011 for biological recultivation |
|-----------------------------------|---------------|----------------------|--------------------------------------------------------------------------------|
|                                   | 2019          | 2020                 | 2019          | 2020          |
| As, mg/kg                         | 1.2           | 2.0                  | 1.6           | 2.1           | no more than 20 |
| Cd, mg/kg                         | 0.3           | 0.3                  | 0.1           | 0.1           | no more than 30 |
| Cr, mg/kg                         | 25.4          | 11.6                 | 24.4          | 19.8          | no more than 1000 |
| Cu, mg/kg                         | 74.3          | 62.7                 | 54.1          | 37            | no more than 750 |
| Ni, mg/kg                         | 15.4          | 11.7                 | 15.2          | 19.3          | no more than 400 |
| Pb, mg/kg                         | 9.8           | 8.9                  | 5.2           | 7.1           | no more than 500 |
| Zn, mg/kg                         | 191           | 112                  | 69.0          | 70.0          | no more than 3500 |
| Total phosphorus, in terms of P2O5, % | 2.8           | 1.6                  | 0.8           | 0.6           | no less than 1.5 |
| Total potassium, in terms of K2O, % | 0.2           | 0.1                  | 0.07          | 0.05          | not rated       |
| Mobile potassium, mg/kg           | 363           | 123                  | 187           | 115           | not rated       |
| Mobile phosphorus, mg / kg        | 220           | 157                  | 80.4          | 29.9          | not rated       |
| Hydrogen index of water extract, units pH | 6.0           | 6.3                  | 7.0           | 6.3           | not rated       |
| Hydrogen index of salt extract, units pH | 5.9           | 6.0                  | 6.1           | 6.1           | 5.0-8.5         |
| Organic matter, %                | 35.8          | 32.0                 | 37.4          | 42.4          | not rated       |
| Total nitrogen %                  | 2.4           | 1.3                  | 1.9           | 2.1           | 0.5             |
| Cation exchange capacity, mmol / 100 g | 58            | 48                   | 54            | 44            | not rated       |
| Hazard class                      | V             | V                    | V             | V             | IV, V           |

As can be seen from the table, the obtained soil complies with GOST R 54534-2011 “Resource conservation. Sewage sludge. Requirements when used for reclamation of disturbed lands”. The
The toxicological properties of the obtained soil and lignin sludge were also studied by the research of the effect on higher plants according to GOST R ISO 22030-2009 “Soil quality. Biological methods. Chronic phytotoxicity to higher plants.” This standard determines chronic phytotoxicity by studying the degree of inhibition by growth soil and reproduction of higher plants under controlled conditions. Two plant species were selected as test objects - fast-growing oil radish (Brassica rapa) and oats (Avena sativa). The experiment took into account such parameters as the number of germinated seeds, the number of live plants, the length of the shoot, dry and wet weight of plants on the 14th day and at the end of the tests, the number of flowers. Plants were planted in containers with 10 seeds of each plant species in four replicates, then, on the 14th day, 4 plants were left in each container. The final harvest of the remaining plants was seven, eight weeks for oats, and five to six weeks for oil radish. As a background control, the soil from uncontaminated areas near the territory of the Solzanskaya industrial site of JSC “BPPM” was chosen. The average results of the experiment are presented in table 2.

Table 2. Chronic phytotoxicity in relation to higher plants.

| Parameters                      | Control   | Obtained soil | Frozen sediment of sludge-lignin |
|---------------------------------|-----------|---------------|----------------------------------|
|                                 | Oats      | Oil radish    | Oats                             | Oil radish |
| Number of germinated seeds      | 10        | 8             | 10                               | 9          | 9          | 8          |
| (out of 10), pcs                |           |               |                                  |            |            |
| Number of live plants on the    | 10        | 8             | 10                               | 9          | 9          | 8          |
| 14th day (out of 10), pcs       |           |               |                                  |            |            |
| Average shoot length on the     | 17.9      | 14.2          | 23.6                             | 16.3       | 14.8       | 10.9       |
| 14th day (per plant), cm        |           |               |                                  |            |            |
| Average wet weight of plants    | 0.20      | 0.24          | 0.24                             | 0.30       | 0.16       | 0.21       |
| on the 14th day (per plant), g. |           |               |                                  |            |            |
| Average dry weight of plants    | 0.045     | 0.064         | 0.10                             | 0.12       | 0.038      | 0.052      |
| at the end of tests (per plant), |           |               |                                  |            |            |
| g.                              |           |               |                                  |            |            |
| Average number of flowers at    | 36        | 16            | 48                               | 27         | 38         | 14         |
| the end of tests (per plant), pcs|          |               |                                  |            |            |

It can be seen from table 2, the obtained soil, as well as the frozen sludge - lignin, do not have a significant negative effect on the germination and sprouting energy of oats and oil radish seeds, which, in contrast to the non-frozen sediment, indicates the absence of acute toxicity of the samples under study. The best results in terms of plant growth and biomass were achieved in the obtained soil - the average shoot length on the 14th day was by 1.3 and 1.1 times higher than the control for oats and oil radish, respectively, and the average dry weight of plants at the end of the tests was by 2.2 and 1.9 times higher than the control for oats and oil radish, respectively. At the same time, the obtained soil increases the ability of plants for reproduction, since the average number of flowers at the end of the tests is by 1.3 and 1.7 times higher than the control for oats and oil radish, respectively. This can also be explained by the fact that the background sample of the soddy-podzolic soil of the Southern Baikal region has a low content of nutrients - up to 7% of organic matter, with a low content of nitrogen, phosphorus, potassium, while the resulting soil contains a large amount of nutrients. Also, the frozen sediment of sludge-lignin does not have chronic toxicity in relation to higher plants, since the decrease in plant growth parameters in relation to the control does not exceed 20%.

In parallel, a field study of the processes of succession was carried out on the dumps of the frozen sludge-lignin sediment. In the first year, a low-intensity self-overgrowth of dumps was observed, mainly with mosses, for example, silver brium (Latin Bryum argenteum), broom dicranum (Dicranum scoparium) and lichens (figure 2a). In the second year of succession, not only the growth of mosses
was observed, but also a number of vascular plants, such as sedge (lat. Carex), stinging nettle (lat. Urtica dioica), coltsfoot (lat. Tussilago), thistle (lat. Cirsium), sow-thistle (Latin Sonchus), while coltsfoot (Latin Tussilago) prevailed (figure 2a). Coltsfoot is a weedy perennial herb that is usually found in areas free from turf with high humidity and pH 5.8-6.7, while, due to its unpretentiousness, it quickly develops free areas, but is subsequently replaced by other plants.

![Figure 2](image-url)  
**Figure 2.** Self-overgrowth of dumps of frozen sludge-lignin sediment in 2019 (a) and 2020 (b).

We also studied the processes of succession on the soil, which was formed on the Solzanskaya industrial site in 2019. In the first year (2019), three different crops were planted in the obtained soil: phacelia (Phacelia), seed oats (Avena sativa) and mustard (Sinapis), in the second year (2020), the soil was left for self-overgrowth. In 2020, in addition to the previously planted crops - phacelia (Phacelia), oats (Avena sativa) and mustard (Sinapis), a number of plants were observed that were found on the frozen sediment of sludge-lignin - sedge (Carex), stinging nettle (Urtica dioica), coltsfoot (Tussilago), thistle (Cirsium). A significant overgrowth of the soil by stinging nettle (Urtica dioica), common oats (Avena sativa), and stellaria media (Stellaria media) was also revealed, which can be explained by the high fertility of the studied soil, as well as the high content of nutrients. Also, in June 2020, strawberry (Fragaria) and raspberry (Rubus idaeus) were planted on the obtained soil, which successfully took root and gave shoots.

3. Conclusion

The carried out field and office studies showed that the obtained soil in its chemical and agrochemical parameters corresponds to GOST 54534-2011 “Resource conservation. Sewage sludge. Requirements for the use of disturbed lands for recultivation”, which means it can be used in technical and biological recultivation of disturbed lands, industrial waste dumps and other applications in accordance with its purpose. At the same time, studies on the chronic phytotoxicity of the obtained soil showed that it promotes an increase in the growth and biomass of plants, and also increases their ability for reproduction. A visual study of the processes of succession also showed that there is a high rate of self-overgrowing with a large, in comparison with the frozen sludge-lignin, biodiversity in the obtained soil. The tests also showed that the dumps of the frozen sludge-lignin sediment are subject to the process of self-growth, albeit less pronounced, while, unlike the original colloidal sediment, it does not have an acute and chronic phytotoxic effect on higher plants.

Thus, the developed concept of the technology of processing sediments of storage cards of JSC BPPM, based on the creation of effective conditions for the processes of their natural freezing, drainage and self-overgrowth, will not only reduce the technical and economic costs of their disposal and increase the socio-ecological safety of the region, but will also allow to obtain a significant additional ecological and economic effect with their further use as soil.
References

[1] Russian Federation. The laws. On environmental protection: [Feder. law: adopted by the State. Duma January 10. 2002: as of 31 Dec. 2017 N 7] (M.: Meeting of the legislation of the Russian Federation) 2002 2 Art. 133

[2] *List of instructions based on the results of checking the implementation of legislation on the conservation of Lake Baikal and its ecological improvement* President of Russia 2019 Retrieved from: http://kremlin.ru/acts/assignments/orders/61524/print

[3] Bogdanov A V, Alekseeva O V, Shatrova A S, Kulakov V A and Shkrabo A I 2019 *A method of freezing colloidal sediments of sludge-lignin by means of trenching* Invention patent RU 717520 C1, 03/23/2020. (Moscow: Rospatent)

[4] Bogdanov A V, Shatrova A S, Alekseeva O V and Kulakov V A 2020 Pilot-industrial tests of the technology of freezing of colloidal sediments of sludge-lignin OJSC "Baikal Pulp and Paper Mill" XXI century. Technosphere safety 5 1(17) 8-20

[5] GOST R 57446-2017 *Best available technologies. Reclamation of disturbed lands and land plots. Restoration of biological diversity* (M.: Standartinform)

[6] Yaltanets I M and Levanov N I 2008 *Handbook on hydromechanization of open pit mining* (M.: Publishing house of MGGU)

[7] Bogdanov A V, Fedotov K V and Shatrova A S 2020 *Development of scientific and technical bases for environmentally safe disposal of accumulated waste from the pulp and paper industry of the Baikal region* (Irkutsk: Publishing house: LLC "Glazkovskaya Printing House")

[8] PND F 16.1: 2.3: 3.11-98 *Quantitative chemical analysis of soils. Methods for measuring the content of metals in solid objects by spectrometry with inductively coupled plasma* (M.: Center for Research and Water Control)

[9] GOST 26213-91 *Soils. Methods for the determination of organic matter* (M.: Publishing house of standards)

[10] GOST R 54650-2011 *Soils. Determination of mobile compounds of phosphorus and potassium by the Kirsanov method modified by CINAO* (M.: Standartinform)

[11] GOST 26107-84 *Soils. Methods for the determination of total nitrogen* (M.: Publishing house of standards)

[12] GOST 26483-85 *Soils. Preparation of a salt extract and determination of its pH by the CINAO method* (M.: Publishing house of standards)

[13] PND F 16.2.2: 2.3: 3.33-02 *Quantitative chemical analysis of soils. Technique for measuring the pH value (pH) of solid and liquid industrial and consumer waste, sediments, sludge, activated sludge, bottom sediments by the potentiometric method* (M.: FGU "Center for Environmental Control and Analysis" of the Ministry of Natural Resources of Russia)