

Analysis of the Composition of Municipal Wastewater Sludge from Small Settlements in East Kazakhstan

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ABSTRACT

One of the greatest environmental problems of modern countries is the pollution of territories with waste. Of particular concern are the wastes generated during the treatment of municipal wastewater, i.e. sewage sludge. They are the inevitable price of urbanization and improved quality of life. As a result of the research conducted, a comprehensive analysis of the composition of municipal sewage sludge was conducted using the example of four small settlements in East Kazakhstan. The results of laboratory studies established the composition of the organic part, biogenic elements, as well as microbiological and parasitological indicators. It was revealed that cadmium, copper, zinc and arsenic are main sources of problems in wastewater treatment plant sludge. For copper and zinc, the standards set by the European Directive 86/278/EEC were exceeded by up to 3.2 and 1.5 times, respectively. At the same time, there is an increased content of nutrients. Organic matter in all studied samples exceeds the minimum established values by 3.5–3.7 times; the potassium content in all studied samples is 5.1–5.6 times higher than the minimum established value for organomineral fertilizers in the Republic of Kazakhstan. The concentration of hydrogen ions (pH) corresponds to neutral. Tests for the determination of microbiological and parasitological parameters indicate that the studied sludge does not contain various pathogenic bacteria and microorganisms.

Keywords: municipal treatment facilities, domestic wastewater, sludge, biogenic elements, organic matter, heavy metals, microbiological indicators.

INTRODUCTION

Under modern conditions, the problem of disposal of sludge from wastewater treatment plants is becoming more acute in the world. Their accumulation in increasing volumes leads to a rapid increase in environmental, social and economic costs due to the extremely low level of utilization. At the same time, in terms of its physicochemical and aggregate composition, sludge is a unique resource that can be used in various industries with significant social, environmental and economic effects. The main indicators characterizing the properties of sludge include humidity, content of organic matter and total nitrogen in sediment samples, the content of heavy metals (gross form) and

others. The main feature of wastewater treatment plant sludge is its two-component nature: the system consists of both organic and mineral components (80% and 20%, respectively, in fresh waste and up to 20% and 80% in waste after long-term storage). However, the presence of heavy metals in the sludge is classified by the legislation of Kazakhstan as waste of class IV [Order, 2021]. Most often, these types of waste are stored and not subject to further processing. Silt sediments also have a complex chemical composition. They contain up to 40% organic and, accordingly, up to 60% mineral matter in terms of dry weight [Nikovskaya et al., 2011]. Organic matter is represented by proteins, which are the main structural component of the cell (up to 50%), carbohydrates (about

20%), humic compounds (up to 17%), as well as uronic and nucleic acids (about 1%) [Lamastra et al., 2018]. Researchers also note a very high content of humic acids in the sludge of wastewater treatment plants, which differ significantly from soil acids, since they additionally contain amino acids and anionic surfactants [Wang et al., 2017]. Sewage sludge is one of the organic wastes that contain a high concentration of phosphorus, in addition to other unwanted substances, such as heavy metals [Nascimento et al., 2020], pathogens and hydrocarbons [Fijalkowski et al., 2017]. Turek et al. presents the content of metals (Cd, Cu, Cr, Pb, Ni and Zn) in the sludge of the municipal wastewater treatment plant located in the Lodz Voivodeship (Poland). The metals were analyzed by flame atomic absorption spectrometry. The metal concentrations did not exceed the normative limit values [Turek et al., 2019].

Tytła analyzed the total concentrations of heavy metals and their chemical forms in the sewage sludge located in the Silesian Voivodeship (Poland). According to the results of the risk analysis carried out on total and specific indices, it was revealed that substances such as Zn, Cd, Ni and Hg pose the greatest environmental hazard among the analyzed heavy metals. It was also noted that the gross concentrations of heavy metals make it possible to assess only the level of sediment contamination, while the mobility, bioavailability and toxicity of elements depend on the chemical forms of their presence. The author of the article made a recommendation that the total concentration and chemical form of heavy metals in sewage sludge should be regularly monitored to prevent the risk of secondary contamination of soils with heavy metals and to identify the potential hazards posed by heavy metals [Tytła, 2019].

Milik et al. studied the total concentrations of trace elements in all sewage sludge from the Pomeranian Voivodeship (Poland). According to their data, the content of cadmium in wastewater was much higher than in other countries. The most common trace elements were copper and zinc [Milik et al., 2017]. The presence of various microorganisms in sewage sludge is also of interest, such as heterotrophic and chemoautotrophic bacteria, saprophytes and pathogens [Zhang et al., 2015]. The characteristics of sewage sludge depend on the degree of pollution and the type of pollutants in the treated wastewater [Iticescu et al., 2021].

The aim of this research was to analyze the composition of municipal sewage sludge from

small settlements in East Kazakhstan for indicators that are critical when using sludge as reclamation agents. The following are the results of a comprehensive analysis of the composition of the sewage sludge from production sites of settlement treatment facilities for household wastewater in the East Kazakhstan region. The results obtained can help in choosing a technology for the safe disposal and beneficial use of sludge. The novelty of the work lies in the fact that the sediments of the treatment facilities of small settlements in East Kazakhstan were for the first time considered in terms of safety for the purposes of reclamation. The scope of work included the analysis of the sediments from wastewater treatment plants of 4 settlements with the highest risks of the presence of toxic metals (located near mining enterprises).

MATERIALS AND METHODS OF RESEARCH

The object of the study was the sludge from municipal treatment facilities of small settlements in East Kazakhstan: Shemonaikha city (including Ust-Talovka village), Zhezkent village, Altaisky village, Belousovka village. The number of inhabitants of these settlements is:

- Shemonaikha and Ust-Talovka – 21416 people.
- Zhezkent – 9371 people.
- Altaisky – 2104 people.
- Belousovka – 9948 people.

The description of technological schemes of treatment facilities of these settlements is given below. The wastewater treatment plant in Shemonaikha and Ust-Talovka has a design capacity of 32,000 m³/day. The actual flow of wastewater for treatment in 2021 was about 4,100 m³/day. The mode of operation is year-round, round the clock. The treatment technology involves mechanical, complete biological treatment with subsequent post-treatment in biological ponds. The treatment facilities include a receiving chamber with gratings, horizontal sand traps, a pre-aerator, primary settling tanks, aerotanks, secondary settling tanks, sludge platforms, and a sand platform. Sludge beds (four pieces measuring 83.0×28.0 m, depth 1.6 m) are asphalt concrete with a drainage system for removing water from the sediment. Sludge maps and sludge treatment facilities in Shemonaikha are shown in Figure 1.



Fig. 1. Sludge maps and sludge treatment facilities in Shemonaikha

The treatment facilities of the Zhezkent village have a design capacity of 5,000 m³/day and an average actual capacity of 2,600 m³/day (according to 2021 data). The operating mode of the treatment facilities is year-round, round-the-clock. The wastewater treatment methods are mechanical and biological treatment, as well as disinfection. The process of mechanical cleaning at the treatment plant is represented by fixed grates with manual cleaning, a sand trap, and primary two-tier settling tanks. The process of biological treatment at the facilities is represented by: air filters (biofilters) and secondary clarifiers. The wastewater that has been treated at the plant is discharged into the storage pond. Sludge beds are designed to dry the sludge formed at all stages of treatment (Figure 2). The number of silt cards is three.

The design capacity of the treatment facilities in the Belousovka village is 1,500 m³/day. The actual flow of wastewater in 2021 was about 1,200 m³/day. The operating mode of the treatment facilities is year-round, round-the-clock. The treatment technology involves mechanical and biological cleaning with further disinfection

by ultraviolet radiation of the bactericidal installation; during the period of repair and scheduled maintenance work at the bactericidal installation, bleach is used for disinfection. The treatment facilities include a receiving chamber with gratings, a sand trap, primary two-tier settling tanks, secondary settling tanks, silt pads, and a sand pad. Two silt pads have an area of 162 m², with asphalt and drainage. The silt maps of treatment facilities at Belousovka are shown in Figure 3.

The technological scheme for the treatment of municipal wastewater in the Altaisky village includes mechanical and biological treatment of household wastewater. The design capacity of the treatment facilities was 2,400 m³/day; the actual load in 2021 was about 800 m³/day. The silt yard consists of four pits: two pits are natural with a total area of 108 m², two non-exploited concrete pits with a total area of 72 m². Sand traps are periodically removed under hydrostatic pressure to silt pads. Decayed sediment from the sludge chamber of the primary two-tier settling tanks is removed under hydrostatic pressure to the sludge platforms. The sludge settled in the secondary



Fig. 2. Silts on the silt maps of the treatment facilities at Zhezkent; a) fresh sludge (no more than 1 week), b) naturally dried sludge (more than 1 month)



Fig. 3. Sludge maps and sludge treatment facilities at the Belousovka village

settling tanks is pumped out by a sewage machine and taken out to the sludge sites (Figure 4). The permitted volumes of sludge formation for treatment facilities of the studied small settlements of East Kazakhstan are shown in Table 1. According to the requirements of local permits, the resulting sludge from the above-mentioned treatment facilities requires disposal.

EXPERIMENTAL PART

To determine the main classification features, silt samples were taken from the silt maps of the above-mentioned treatment facilities. The collected samples were sent to the laboratories:

- Testing laboratory (center) of the federal budgetary healthcare institution “Center for Hygiene and Epidemiology in the Altai Territory” of the Ministry of Agriculture of the Russian Federation (CAS “Altaisky”), Barnaul, Russia;
- Analytical Research Laboratory of the Center of Excellence “VERITAS” of D. Serikbayev East Kazakhstan Technical University (LAR “Veritas”), Ust-Kamenogorsk, Kazakhstan;
- Testing laboratory of the regional state budgetary institution “Altai Regional Veterinary Center for the Prevention and Diagnosis of Animal Diseases” (TL “ARVC”), Barnaul, Russia.

Sampling was carried out according to the standardized procedure GOST 17.4.4.02-2017.



Fig 4. Sludge maps and sludge treatment facilities at the Altaisky village

Table 1. Annual volumes of sludge formation of treatment facilities (according to permits)

| Wastewater treatment plant | Sediment volume, tons/year | Waste volume, m ³ /year | Sediment/runoff ratio |
|-----------------------------|----------------------------|------------------------------------|-----------------------|
| Shemonaikha and Ust-Talovka | 362.2 | 1 926.6 | 0.19 |
| Zhezkent | 289.1 | 1 430.7 | 0.2 |
| Belousovka | 47.8 | 427.4 | 0.11 |
| Altaisky | 11.7 | 340.7 | 0.03 |
| Total | 710.8 | 4 125.4 | 0.17 |

Nature protection. Soils. Methods for sampling and preparation of soil for chemical, bacteriological, helminthological analysis. The list of defined indicators for laboratories is given in Table 2. To determine the content of heavy metals in the composition of sewage sludge, D. Serikbayev EKTU used an inductively coupled plasma mass spectrometer ICP-MS Agilent 7500cx (USA). The research results are presented in Table 3. The results of testing microbiological indicators are shown in

Tables 4 and 5. The results of the tests conducted in the analytical research laboratory of the VERITAS Center of Excellence of D. Serikbayev East Kazakhstan Technical University are given in Table 6.

RESULTS AND DISCUSSION

It was revealed that cadmium, copper, zinc and arsenic are the main sources of problems in

Table 2. List of indicators determined in laboratories

| Indicator | CAS "Altaysky" | LAR "Veritas" | TL "ARVC" |
|--------------------|---|--------------------------------|--|
| Number of samples | 4 | 4 | 4 |
| Defined indicators | pH, N _{total} , P _{total} , K _{total} , organic matter, Cd, Cu, As, Ni, Hg, Pb, Zn | Cr, Ni, Cu, Zn, As, Cd, Hg, Pb | Coliform bacteria (coliforms), pathogenic microorganisms, including salmonella |

Table 3. Test results of sewage sludge

| Indicators | Wastewater treatment plant | | | | GOST R 54651-2011 | ST RK 2578–2014 | |
|----------------------|----------------------------|--------------------|------------------|----------|-------------------|-----------------|-----------------------|
| | Shemonaikha village | Belousovka village | Altaysky village | Zhezkent | Norm* | Norm** | Conformity assessment |
| pH of water extract | 4.9 | 6.8 | 6.3 | 6.2 | 6.0–8.0 | 5.5–8.5 | Compliant |
| N _{total} % | 0.53 | 0.47 | 0.82 | 0.54 | 0.6 | 0.6 | Above the norm |
| P _{total} % | 2.41 | 1.18 | 1.51 | 1.07 | 0.7 | 1.5 | Above the norm |
| K _{total} % | 0.52 | 0.51 | 0.59 | 0.56 | 0.1 | - | - |
| Organic matter % | 68.76 | 62.68 | 64.00 | 74.3 | 30 | 20 | Above the norm |
| Cd, mg/kg | 2.27 | 6.14 | 4.09 | 6.07 | 15.0 | 15.0 | Compliant |
| Cu, mg/kg | 221.01 | 230.49 | 227.85 | 228.34 | 750.0 | 750.0 | Compliant |
| As, mg/kg | 1.97 | 5.4 | 5.06 | 5.2 | 10.0 | 10.0 | Compliant |
| Ni, mg/kg | 117.5 | 162.3 | 132.4 | 123.0 | 200.0 | 200.0 | Compliant |
| Hg, mg/kg | 0.0328 | 0.04 | 0.0374 | 0.0352 | 7.5 | 7.5 | Compliant |
| Pb, mg/kg | 139.41 | 194.8 | 151.84 | 142.8 | 250.0 | 250.0 | Compliant |
| Zn, mg/kg | 79.59 | 81.39 | 80.44 | 79.31 | 1750.0 | 1750.0 | Compliant |

* For use under all types of crops, except for vegetables, mushrooms, greens and strawberries in the Republic of Kazakhstan.

** For use for planting forestry crops along roads, in nurseries of forest and ornamental crops, floriculture, for the cultivation of depleted soils, the reclamation of disturbed lands and slopes of roads, the reclamation of solid domestic waste dumps in the Russian Federation.

Table 4. Results of microbiological indicators of sludge treatment facilities, GOST R 54651–2011

| Indicators | Treatment facilities | | | | GOST R 54651–2011 | |
|--|----------------------|--------------------|------------------|--------------|-------------------|-----------------------|
| | Shemonaikha village | Belousovka village | Altaysky village | Zhezkent | Norm | Conformity assessment |
| Coliform bacteria (coliforms) | Not detected | Not detected | Not detected | Not detected | Not allowed | Compliant |
| Pathogenic microorganisms incl. salmonella | Not detected | Not detected | Not detected | Not detected | Not allowed | Compliant |

Table 5. Results of microbiological indicators of sludge of treatment facilities, ST RK 2578–2014

| Indicators | Treatment facilities | | | | ST RK 2578–2014 | |
|--|----------------------|--------------------|------------------|--------------|-----------------|-----------------------|
| | Shemonaikha village | Belousovka village | Altaisky village | Zhezkent | Norm | Conformity assessment |
| Coliform bacteria (coliforms) | Not detected | Not detected | Not detected | Not detected | 100/1000 | Compliant |
| Pathogenic microorganisms incl. salmonella | Not detected | Not detected | Not detected | Not detected | Absence | Compliant |

Table 6. Results of tests for compliance with the standards of the European Union and the Russian Federation

| Sample | Cr | Ni | Cu | Zn | As | Cd | Hg | Pb |
|---|-----------|-----------|------------------------|------------------------|------------------------|------------------------|-----------|-----------|
| | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| Sample No. 1 (Shemonaikha) | 182.8 | 87.70 | 2042 | 6724 | 45.10 | 37.15 | 0.10 | 385.4 |
| Sample No. 2 (Belousovka) | 222.6 | 88.73 | 1677 | 3476 | 30.30 | 20.47 | 1.20 | 478.3 |
| Sample No. 3 (Altaisky) | 174.1 | 79.00 | 1930 | 3346 | 60.50 | 25.31 | 1.20 | 313.6 |
| Sample No. 4 (Zhezkent) | 186.1 | 82.23 | 5650 | 4447 | 234.8 | 25.85 | 3.11 | 1994.4 |
| Norm (Table 1) GOST R 54651-2011 | 500 | 200 | 750 | 1750 | 10 | 15 | 7.5 | 250 |
| Directive 86/278/EEC | - | 300–400 | 1000–1750 | 2500–4000 | - | 20–40 | 16–25 | 750–1200 |
| Norm (Appendix 13) SanRN 2.1.7.573–96. | 1200 | 400 | 1500 | 4000 | 20 | 30 | 15 | 1000 |
| ST RK 2578–2014 | 500 | 200 | 750 | 1750 | 10 | 15 | 7.5 | 250 |
| Assessment of compliance with normative documents | Compliant | Compliant | Doesn't meet standards | Doesn't meet standards | Doesn't meet standards | Doesn't meet standards | Compliant | Compliant |

wastewater treatment plant sludge. For copper and zinc, the standards established by the European Directive 86/278/EEC were exceeded by up to 3.2 and 1.5 times, respectively (Table 6). Two most likely reasons were assumed: 1) the excess is a consequence of the ingress of wastewater from industrial sites of mining enterprises located nearby to the treatment plant [Aubakirova et al., 2018], 2) the initial high content of cadmium, copper, zinc and arsenic at the inlet to the water supply system. At the same time, there is an increased content of nutrients. Organic matter in all studied samples exceeds the minimum established values by 3.5–3.7 times; the potassium content in all studied samples is 5.1–5.6 times higher than the minimum established value for organomineral fertilizers in the Republic of Kazakhstan (Table 3). In terms of total nitrogen in the composition of the sediments of the Altai village, an excess of the norm by 1.37 times was observed (Table 3). The composition of sewage sludge from the city of Shemonaikha is 1.6 times higher than the norm by phosphorus according to the ST RK 2578–2014

standard (Table 3). The concentration of hydrogen ions (pH) corresponds to neutral (Table 3). The tests for the determination of microbiological and parasitological parameters indicate that the studied sludge does not contain various pathogenic bacteria and microorganisms (Table 4).

The samples of the studied sludge from treatment facilities are subjected to disinfestation and do not contain viable helminth eggs or cysts of pathogenic intestinal protozoa (Table 5). The disinfestation method involved composting.

CONCLUSIONS

For the safe storage and further use of sewage sludge as a raw material, as well as usage in the national economy in various industries, it is necessary to have the basic information on their properties and characteristics. The results of the analysis allowed stating that the sludge from the treatment facilities of the studied small settlements can be involved in the economic circulation with the

production of a useful product, but only after additional processing (drying, deposition, etc.). It is important to emphasize that the main criteria for choosing a technology for further processing of sediments from small settlements should be the ease of processing and the possibility of using the products obtained on site.

According to the results of the analysis of the composition of sludge, most of it falls on the organic component, which predetermines the wide possibilities for using the sludge from municipal treatment facilities in small settlements, primarily for reclamation and increasing land fertility.

To implement the idea of involving wastewater treatment plant sludge in the economic circulation, the following measures are recommended:

- to conduct a study of the composition of waste from public utilities and justify the method of their processing to obtain recultivants;
- to estimate the required volume of activities for the reclamation of dumps and quarries. The problem is solved by collecting and analyzing statistical data at mining enterprises;
- to develop the technological schemes for obtaining recultivants.
- to conduct a simulation of the processes of disinfection and stabilization of sediments;
- to determine the conditions for the use of recultivants at specific sites. To calculate the consumption of the reclamation agent, the required soil substrate; to determine the plants contributing to the reclamation of the selected objects.

The implementation of the recommendations will make it possible to develop new types of reclamation agents for mining enterprises.

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