

Article

Pilot Study on the Possibility of Improving Water Treatment Sludge Management in Almaty

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Abstract: This article presents the results of a pilot study on the treatment of sludge from a water treatment plant in the city of Almaty, Republic of Kazakhstan, to ensure further disposal. The main objective of the study was to compare the efficiency of sludge drying by natural and artificial methods. The qualitative characteristics of the leachate from the dewatering unit, the chemical composition of the dried sludge and the granulometric analysis of the dried sludge were also studied. The greatest reduction in moisture content was recorded for drying in natural conditions (2.1%), but this process required the longest drying time. The leachate obtained from sludge dewatering was characterized by significant contamination (e.g., turbidity—55.65 on average, color—67.7, total Fe—5.15 mg/L, total N—79.6 mg/L, COD—311 mg/L, BOD—336.15 mg/L), which indicates the need for its pretreatment before further management in the technological system of the treatment station. The content of chemical substances contained in the dry residue of the sludge was also determined, of which aluminum was 0.94–13.8 mg/kg, silicon was 50.24–146.3 mg/kg, potassium was 1.72–5.51 mg/kg, calcium was 71.8–79.1 mg/kg, iron was 2.0–7.54 mg/kg and nickel was 0.9–4.4 mg/kg. A particle size analysis of the dried sludge showed that the majority fractions were fine and very fine sand, with a total of 20.2%, and silt and clay, with a total of 78.3%. Such properties justify the rationality of considering the reuse of dried sludge as a raw material for making, for example, construction materials or soil remediation material.



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Keywords: water treatment sludge; dewatering; sludge drying; reuse

1. Introduction

Supplying the population with drinking water in sufficient quantities has important social, sanitary and hygienic significance and protects people from epidemic diseases spread through water [1]. The unit processes and equipment used in a water treatment plant (WTP) depend on the water treatment technology adopted, which in turn is determined by the quality of the water source and the formal requirements for the quality of drinking water [2].

Surface water is the main source of drinking water in many regions of the world. It contains various dissolved, colloidal and coarse-dispersed substances, bacteria, and plant and animal organisms. Before supplying the water distribution network, these waters are subjected to special treatment—a set of technological processes to bring their quality into compliance with the applicable formal requirements. Flocculation and coagulation processes are commonly used in surface water treatment technology; however, they generate significant amounts of sludge. The resulting sludge is a high-moisture mass of organic and mineral substances of varying dispersion. In the scientific literature, this waste is usually called natural water sludge, waterworks sludge, and water treatment sludge (WTS) [3,4].

Sludge often poses a certain danger to the environment and humans, since the substances it contains, under specific conditions, can be included in geochemical and biogeochemical cycles [5]. To prevent it having harmful effects on the environment, sludge needs

to be processed, the purpose of which is to reduce its moisture content to a level that allows further disposal.

The choice of a specific sludge treatment technology depends on its properties, regional possibilities for placement, and the creation and operation of appropriate workshops, production facilities and plants. The main technological indicator of sludge, which determines the choice of method used for its processing and dewatering, is its water yield, characterized by the specific filtration resistance [6].

A general process chart demonstrating the different methods and techniques used in sludge management and the order in which they may be arranged and grouped to formulate a comprehensive treatment system is outlined in Figure 1 [7].

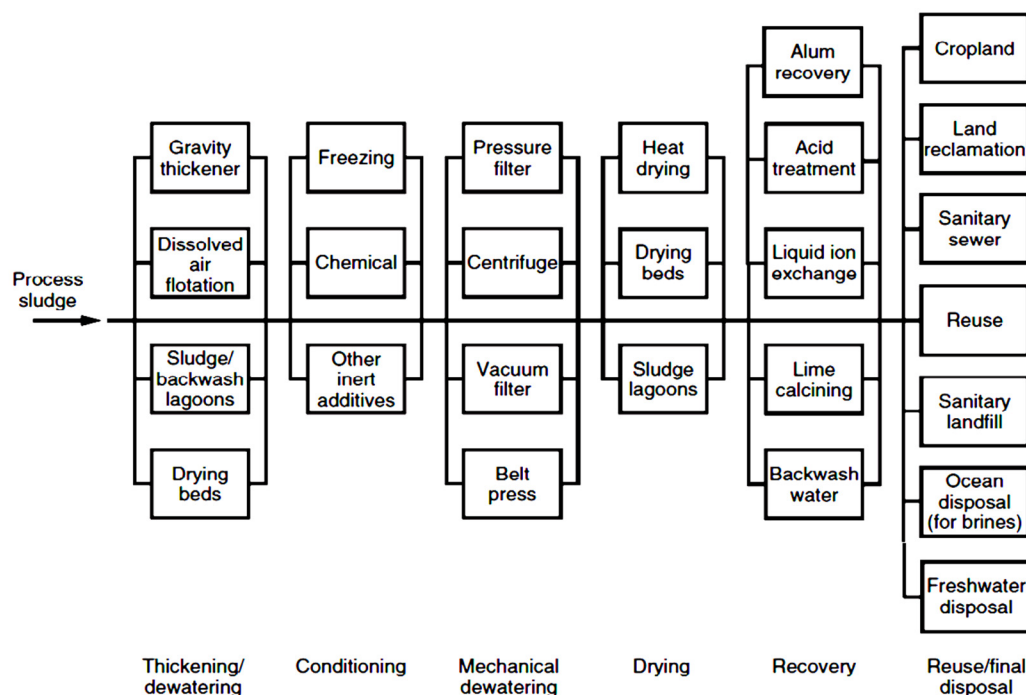


Figure 1. Unit operations and processes for the management of water treatment sludge.

Almost any sludge treatment scheme begins with preliminary compaction, which is due to its high initial moisture content [8].

Conditioning is a process used in many sludge handling systems to enhance the efficiency of the dewatering process. The conditioning of WTS is commonly performed by either chemical or physical conditioning [9].

Natural dewatering has become quite widespread in sludge treatment practice. Examples of non-mechanical dewatering techniques include lagooning, drying on sand beds, natural or artificial freezing and thawing [10].

The mechanical dewatering of water sludge is carried out using vacuum filters, filter presses, centrifuges and other devices. The main factors to consider when choosing a mechanical process for dewatering tap sludge are the number of mineral impurities and the type of chemicals used for coagulation. Generally, the ease of performing the dewatering process is directly proportional to the turbidity of the water and the amount of sludge produced. If the water is softened, the sludge may contain large amounts of calcium carbonates, in which case it will be ideal for dewatering. However, almost all mechanical dewatering systems usually require preconditioning [11].

As for the final management of sludge from WTPs, the most common methods are discharging sludge directly into the sewer system and surface water, and landfilling [11], which clearly do not meet the present-day need for sustainable development. Therefore, in recent years, the attention of many researchers has been focused on methods for sludge end-use that take into account the principles of sustainability and the circular economy [5,12,13].

Among these methods, Nguyen [13] identified the following areas of sludge reuse from WTPs: as a pollutant adsorbent, in land-based applications and in construction materials. Due to the mineralogical properties of WTS, which are similar to natural soil (clay) [14], the partial replacement of natural components with dried WTS in the production of, for example, cement, clinker, bricks, or in geotechnical works, may be an economically rational and environmentally sound choice [15,16].

The available literature lacks a comparison of different methods of drying sludge from WTPs, which is a prerequisite for its potential use in construction and geotechnical work. Therefore, this article presents studies on the dewatering and drying of sludge using natural and artificial methods to determine the effectiveness of moisture reduction and the duration of the process, and also identify factors that impede successful moisture transfer. An analysis of the chemical composition of the filtrate from dewatering and the dried sludge was also carried out, as well as a granulometric analysis of the sludge to confirm its suitability for the construction industry.

2. Materials and Methods

Almaty is a city of republican significance and the largest populated area of the Republic of Kazakhstan, the former capital of Kazakhstan. The population of the city as of June 2024 was 2253.5 thousand people [17].

The climate of Almaty is continental and is characterized by the influence of mountain–valley circulation, which is especially evident in the northern part of the city, located directly in the zone of transition from mountain slopes to the plain.

The average long-term air temperature is +10 °C; the coldest month (January) is −4.7 °C and the warmest month (July) is 23.8 °C. Frosts on average begin on 14 October and end on 18 April. Stable frosts last an average of 67 days—from 19 December to 23 February. Temperatures above 30 °C are observed, on average, 36 days a year [18].

The water supply and sanitation services of the city of Almaty are provided by the State Municipal Enterprise “Almaty Su”. The city of Almaty is supplied with water from 4 main water sources: the Bolshaya and Malaya Almatinka rivers, as well as wells from underground water intakes of the Almaty and Talgar fields. The capacity of all water intakes is 1343 thousand m³/day [19].

The water intake on the Bolshaya Almatinka River with the treatment plant is the main source of water supply for the city of Almaty and provides about 35% of the city’s drinking water. The quality of water in the river is generally good; however, there are significant fluctuations in turbidity and bacteriological indicators. Therefore, raw water treatment is necessary to provide safe drinking water to the city’s residents (Table 1). For this reason, water from the intake is delivered to the Almaty Main Water Treatment Plant (AMWTP), which is located in the southwestern part of the city of Almaty on the right bank of the Bolshaya Almatinka River, in an area with a slight slope from southwest to northeast. The design maximum capacity of the AMWTP is 254 thousand m³/day [20].

After preliminary treatment at water intake structures, water flows by gravity through three pipelines with diameters of 700, 800 and 1000 mm into the distribution chamber. The technological diagram of the AMWTP is shown in Figure 2.

Coagulants are introduced into the distribution chamber, and in case of increased bacterial contamination, the incoming water is pre-chlorinated in the distribution chamber. Aluminum sulfate Al₂(SO₄)₃ and ferric chloride FeCl₃ are used as coagulants. Flocculants (polyacrylamide) are used to intensify the coagulation process in the warm season, and construction lime is used for alkalization.

The distribution chamber is divided into 3 sections. From one section, water is directed to radial sedimentation tanks with spiral guides; from the second section, it is directed to vertical sedimentation tanks. From the third section, water is directed through drum sieves to horizontal sedimentation tanks. Water distribution among sections is carried out manually using gate valves. The water clarified after the sedimentation tanks is

delivered to fast filter stations (2 sets—second and third stage, depending on the time of their construction).

Table 1. Qualitative characteristics of raw water from Bolshaya Almatinka River.

Parameter	Range	Drinking Water Standard
Temperature, °C	0.8–13	–
Turbidity, mg/L	0.2–140	1.5
Color, deg	0–13	20
Odor at 20 °C, points	nd.	2
pH	7.7–8.4	6–9
Permanganate index, mgO ₂ /L	0.42	5.0
Total hardness, mgEq/L	1.1–2.3	7.0
Chlorides, mg/L	0.6–7.3	350
Sulfates, mg/L	3.5–12.0	500
Nitrates, mg/L	1.2–4.4	45.0
Fluorides, mg/L	0.5–1.0	1.5
Aluminum, mg/L	0.02–0.25	0.5
Boron, mg/L	0.006–0.09	0.5
Copper, mg/L	0.02–0.2	1.0
Iron, mg/L	0.1–0.2	0.3
Manganese, mg/L	<0.01	0.1
Nickel, mg/L	<0.005	0.1
Total microbial count, CFU/mL	3–900	50

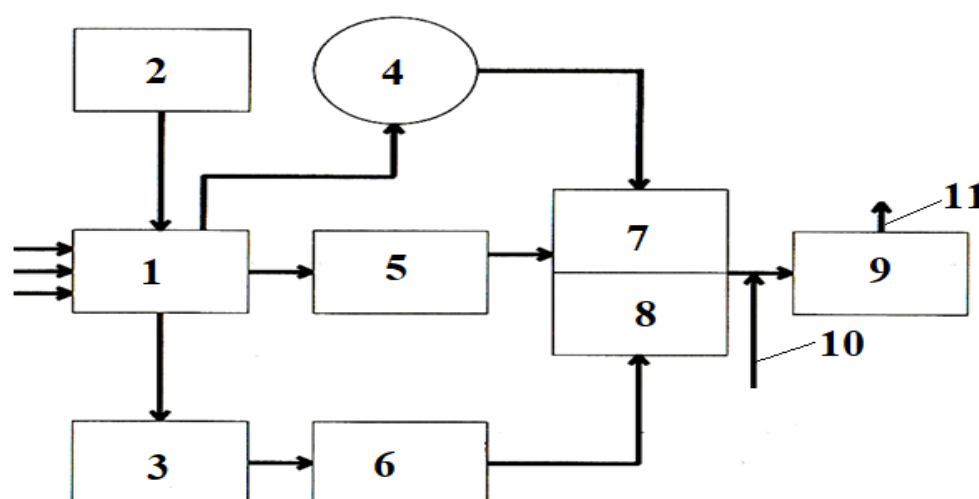


Figure 2. Technological diagram of the Almaty Main Water Treatment Plant: 1—distribution chamber; 2—reagent facilities; 3—drum sieves; 4—radial sedimentation tanks with spiral guides; 5—vertical sedimentation tanks; 6—horizontal sedimentation tanks; 7, 8—fast filters; 9—clean water tanks; 10—disinfectant addition (sodium hypochlorite); 11—water supply to consumers.

Purified water (after filtering) is delivered to clean water tanks, where sodium hypochlorite solution is added for disinfection. The treated and disinfected water is partly by gravity and partly by pumps supplied to the water distribution network.

In the AMWTP, sludge is formed in radial sedimentation tanks with spiral guides, in vertical sedimentation tanks, and in horizontal sedimentation tanks. The sludge from the sedimentation tanks is discharged under hydrostatic pressure directly to the municipal sewer system. Discharging sludge into the municipal sewer system and then processing it at a wastewater treatment plant is currently the only way to manage sludge from AMWTP. Although some authors point out that such a “combined” solution could be economically justified [21], it is certainly not a sustainable solution.

In 2023, we conducted experimental studies on sludge dewatering and drying using natural and artificial methods to determine the effectiveness of moisture reduction and

the duration of the process, and also identify the factors that impede successful moisture transfer. The purpose of these studies was to optimize the process of treating sludge from the MWTP in the city of Almaty, while ensuring its effective drying to a level allowing for further disposal.

A pilot-scale experimental installation was installed on the territory of the Satbayev University in Almaty. The technological diagram of the experimental installation is presented in Figure 3.

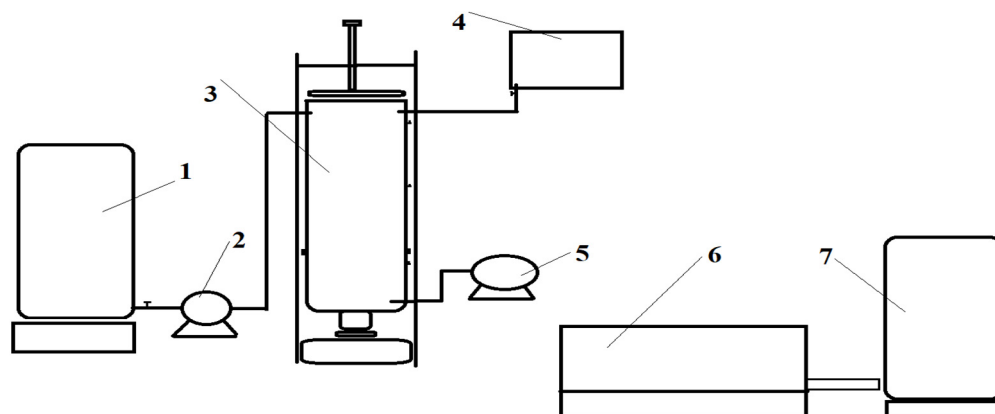


Figure 3. Technological diagram of the experimental installation: 1—storage tank for the raw sludge; 2—pump; 3—sludge thickener/decanter; 4—container for flocculant; 5—compressor; 6—sludge dryer; 7—dried sludge storage.

The raw sludge for experiments was delivered from the horizontal sedimentation tank of the AMWTP in a volume of 850 L. The sludge was collected manually in accordance with the State Standard GOST 56226-2014 [22].

The raw sludge from the storage tank was loaded into a dual-function dewatering unit with a volume of 222 L. At the first stage, the unit was working in the thickening mode as a thickener. From the flocculant container, a 0.1% solution of the flocculant “Praestol 650 TR” (Solenis LLC, Wilmington DE, USA), at a dose of 30 mg/L, was introduced into the device. The preparation of the working solution of the flocculant was carried out as follows: a sample of the flocculant was soaked in distilled water with stirring. Then, the solution was left for a day to mature. After this, the finished flocculant was introduced at the set dose into the sludge. Air from a compressor was supplied to the thickener at the same time to ensure complete contact and thorough mixing. The mixing time was 20 min. After mixing, the dewatering unit operated in thickening mode; the duration of thickening depends on the type of sludge and the design of the thickener. In this case, the thickening duration was 12 h.

Next, the device operated in sludge dewatering mode, as a decanter centrifuge. For this purpose, the unit was equipped with a drum and filter surface mounted on a shaft. Due to the rotation and vibration of the drum with a filter surface, the sludge fills the lower part of the unit, and decanted water (filtrate), as a result of filtration, fills the upper part of the unit. To sample the filtrate for analyses, the device is equipped with sampling ports with valves.

To discharge dewatered sludge, the unit has a technical hatch with a lid sealed with a rubber gasket. The dewatered sludge is discharged to a sludge drying facility.

According to the operating modes of the experimental installation, the sludge was dried under the following conditions:

1. Drying the sludge under natural conditions. The drying of sludge in summer was carried out in the open air on a concrete roofed surface, at an average air temperature of 25–38 °C, for 15 days with periodic turning.
2. Drying the sludge on the heated floor at a temperature of 35 °C. The temperature in the dryer was controlled using a thermostat. The drying time was 13 days.

3. Drying the sludge on the heated floor at a temperature of 45 °C. The drying time was 10.5 days.
4. Drying the sludge in an oven at 80 °C. The drying cabinet ShS-40-02 SPU (Smolenskoye SKTB SPU, Smolensk, Russia) is designed for the drying, heat treatment and testing of materials, products and samples. The sludge inside the dryer was heated to 80 °C. The drying time was 3 days.
5. Drying the sludge in an oven at a temperature of 120 °C. The sludge inside the dryer was heated to 120 °C. The drying time was 3 days.

After drying, the dry sludge was sent to a storage tank. A plastic container was used as a storage unit in the experimental installation.

The sludge analyses were carried out according to standard methods. First, the moisture content of the sludge after dewatering and after drying was determined using the gravimetric method [23]. The chemical composition of the filtrate obtained from sludge dewatering was also determined. In accordance with the general rules, sampling was carried out manually [24]. To analyze the chemical composition of the filtrate, the following indicators were determined: temperature, turbidity, color, odor at 20 °C, flavor, pH value, permanganate oxidation, total hardness, aluminum, beryllium, boron, total iron, cadmium, manganese, copper, nickel, nitrates, lead, selenium, sulfates, fluorides, suspended substances, COD, BOD, and total microbial count.

General indicators, including the temperature and odor, were determined according to the ST RK 3060-2017 method [25], the hydrogen index was determined according to ST RK ISO 10523-2013 [26], permanganate oxidation was determined according to ST RK 1498-2006 [27] and the total hardness was determined according to ST RK 1514-2006 [28]. Aluminum, beryllium, boron, total iron, cadmium, manganese, copper, nickel, lead, selenium, and hexavalent chromium were determined by atomic spectrometry methods [29]. The turbidity and taste were determined according to the GOST 3351-74* method [30], and color according to the GOST 31868-2012 method [31]. The spectrometric method was used to determine nitrates in water [32], and the gravimetric method was used to determine sulfates [33]. Fluorides were determined according to the method set out in ST RK 2727-2015 "Water Quality Method for determining fluorides" [34]. Chlorides were determined according to the GOST 4245-72 method [35]; to determine suspended substances in water, we used the gravimetric method set out in ST RK 3068-2017 "Water Quality. Gravimetric method for measuring suspended substances and total impurities" [36]. The chemical oxygen demand (COD) was determined according to the ST RK 1322-2005 method [37], and the biological oxygen demand (BOD) according to the ST RK 5815-1-2010 method [38].

Next, we determined the granulometric composition of the dried sludge; for this, we used the methodology set out in GOST 12536-2014 "Interstate standard for soils. Methods for laboratory determination of granulometric (grain) and microaggregate composition" [39]. Samples of dried sludge were also collected (Figure 4) to determine their chemical composition using the following indicators: aluminum, magnesium, phosphorus, sulfur, silicon, potassium, calcium, titanium, chromium, manganese, iron, nickel, copper, zinc, bromine, strontium and lead.

Aluminum, magnesium, silicon, titanium, iron, calcium and manganese were determined by the atomic absorption method [40], and sulfur was determined by the elemental sulfite method [41]. Phosphorus and potassium were determined according to the method set out in GOST 26204-91 [42], and the content of chromium, copper, lead, nickel and zinc according to the method set out in ST RK 11047-2008 [43].

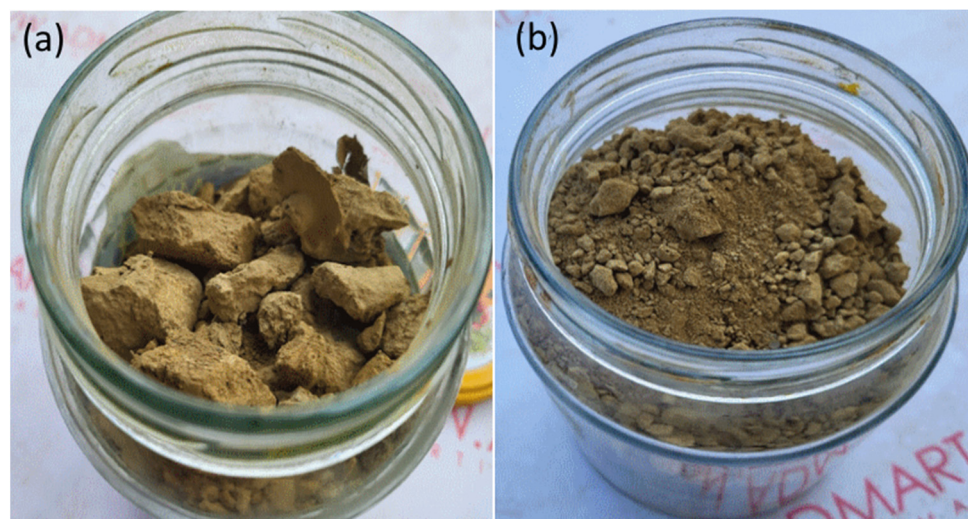


Figure 4. Example samples of dried sludge: sludge dried in natural conditions (a) and sludge dried at 80 °C (b).

3. Results

The thickening and dewatering of WTS generate another residuals, namely the supernatant and filtrate, which are typically recycled or discharged by the treatment plant [11]. To estimate the potential technological or environmental impact of this additional residual stream, we took 10 samples of the filtrate from the thickening/decanting unit. The results of the analyses are presented in Table 2 as descriptive statistics estimated from measurements.

Table 2. Qualitative characteristics of filtrate from the dewatering of WTS.

Parameter	Minimum	Maximum	Average	Median	Percentile 25	Percentile 75
Temperature, °C	8.4	22	13.34	10.5	9.425	18.2
Turbidity, mg/L	50.4	62.3	55.65	53.95	51.825	60.75
Color, degree	58	71	67.7	70	68.25	70
Odor at 20°, points	6	8	7.6	8	7.25	8
pH	7	7.5	7.33	7.35	7.3	7.4
Permanganate index, mg O ₂ /L	3.9	4.9	4.5	4.55	4.275	4.775
Total hardness, mgEq/L	4.3	6.7	5.2	5	4.55	5.675
Aluminum, mg/L	0.32	0.61	0.534	0.56	0.53	0.5975
Beryllium, mg/L	<0.0001	<0.0001	-	-	-	-
Boron, mg/L	0.0001	0.004	0.00234	0.002	0.002	0.003
Total iron, mg/L	1.292	7.1	5.1451	5.8	4.775	6.18975
Cadmium, mg/L	0.00003	0.0004	0.00019	0.0001	0.0001	0.0004
Manganese, mg/L	0.00001	0.002	0.00141	0.0016	0.001325	0.001775
Copper, mg/L	0.0007	0.003	0.00227	0.002	0.002	0.003
Nickel, mg/L	0.00015	0.004	0.00113	0.0004	0.0003	0.001925
Nitrates, mg/L	0.03	1.6	0.59	0.43	0.04	1.05
Lead, mg/L	0.003	0.007	0.00505	0.005	0.004	0.006075
Selenium, mg/L	0.0002	0.0014	0.00055	0.0003	0.000233	0.00075
Sulfates, mg/L	30	54.3	42.78	44.05	37.7	47.725
Fluorides, mg/L	0.2	0.42	0.303	0.3	0.225	0.3775
Chlorides, mg/L	175.5	254.6	224.76	231.15	219.025	239.675
Hexavalent chromium, mg/L	0.02	0.042	0.0331	0.038	0.02375	0.04

Table 2. Cont.

Parameter	Minimum	Maximum	Average	Median	Percentile 25	Percentile 75
Residual chlorine, mg/L	0.01	0.3	0.094	0.079	0.072	0.08675
Total nitrogen, mg/L	73.2	84.6	79.59	79.5	78.6	81.15
Suspended substances, mg/L	138.9	167.8	147.175	143.75	141.275	147.675
COD, mg/L	248.6	374.8	311.06	300.9	271.6	360.35
BOD, mg/L	218.4	416.8	336.15	342.2	318.7	375.375
Total microbial count, CFU/mL	7000	100,000	88,100	100,000	92,500	100,000

Data on the chemical composition of the collected samples showed that the filtrate contains various mineral and organic compounds. High values of turbidity (50.4–62.3 mg/L), color (60–71 degrees), total iron (1.292–6.8 mg/L), COD (263.6–328.7 mg/L), BOD (218.4–416.8 mg/L) and total microbial count (7000–100,000 CFU/mL) indicate that the recycling of the filtrate to the head of the water treatment plant increases the contamination of the treated water and that preliminary treatment is required to clarify, discolor and oxidize the filtrate.

The thermal drying of water treatment sludge is the process of reducing the volume of wet solids by removing water and achieving a dry solids concentration greater than 90%. This process also stabilizes the final product in dry granular form, making it easy to store, ship, use or dispose of.

To determine the moisture content of the treated sludge, we took samples of the raw sludge from the AMWTP, sludge after the thickener and sludge after the dryer. The average values of moisture content in the examined WTS samples are presented in Table 3.

Table 3. Moisture content and volume reduction in different forms of the WTS.

Form of the Sludge	Moisture Content, %	Relative Volume
Raw sludge	90	1.00
Thickened sludge after 12 h of thickening	84	0.6250
Sludge after dewatering	63	0.2703
Sludge after drying under natural conditions at temperatures 25–38 °C (15 d)	2.1	0.1021
Sludge after drying on a heated floor at a temperature of 35 °C (13.5 d)	2.4	0.1025
Sludge after drying on a heated floor at a temperature of 45 °C (12 d)	2.2	0.1022
Sludge after drying in an oven at 80 °C (3 d)	2.9	0.1030
Sludge after drying in an oven at 120 °C (3 d)	2.45	0.1025

Based on the results of the moisture content analyses, it can be concluded that the WTS from the AMWTP has a good susceptibility to dewatering; in the case of thickening, the moisture content decreased on average from 90% to 86%, and mechanical dewatering caused a further reduction to a value of 64%. Decreasing the volume of water in the sludge while increasing the solids content is one of the principal objectives of sludge management systems, as the volume of sludge is reduced, thereby reducing the cost of further sludge treatment and disposal. The data in Table 3 show that the WTS analyzed after mechanical dewatering has only 27% of its initial volume, which is further reduced to 10% of its initial volume after drying.

The highest moisture content reduction was observed for drying in natural conditions. Such a result may have been influenced by the longest drying time (15 days) and the high outdoor air temperature in the summer season; the average daily temperature during the study period was 25–38 °C (Figure 5).

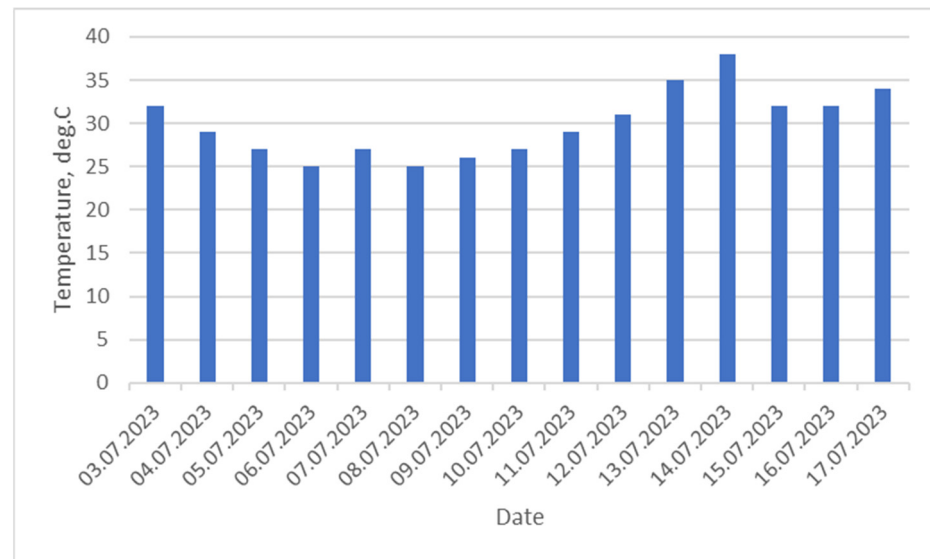


Figure 5. Average daily temperatures in Almaty during study period.

The sludge after drying using a heated floor at a temperature of 35 °C had a moisture content of 2.4%; at a temperature of 45 °C, the moisture content was 2.2%. When drying the sludge in an oven at a temperature of 80 °C, the moisture content was 2.9%, and at a temperature of 120 °C, it was 2.45%; meanwhile, at 120 °C, the burning of the top layer of the sludge was observed with a corresponding burning smell.

To determine the granulometric composition of the treated sludge, we took samples of sludge after drying. Averaged data representing the particle size distribution of sludge after drying in different conditions are presented in Figure 6.

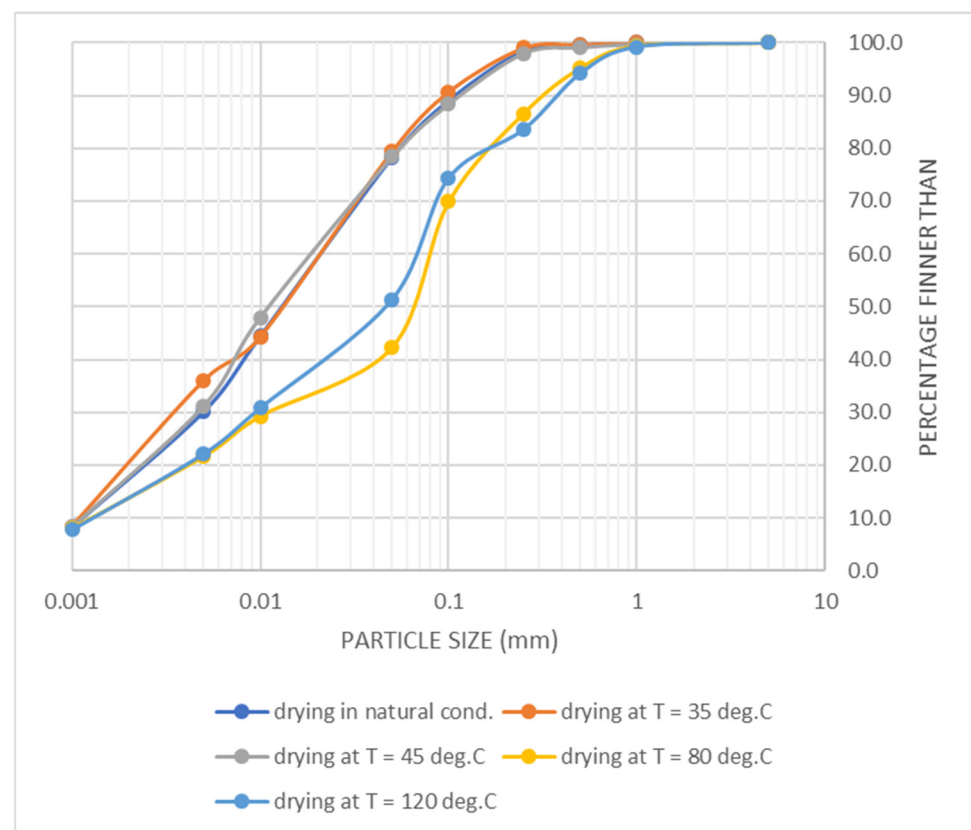


Figure 6. Cumulative particle size distribution of WTS after drying.

According to the interstate standard GOST 12536-2014 [39], all mechanical soil elements with a size less than 0.05 mm are regarded as physical clay and silt, while sizes between 0.05 mm and 1.0 mm are regarded as physical sand. In addition, particles larger than 1 mm are distinguished as rock fragments (gravel and stones). Another classification was proposed by the U.S. Department of Agriculture (USDA) [44] and is used in geotechnical studies all over the world. According to the USDA, particles less than 0.05 mm are determined as clay and slit, those between 0.05 and 2 mm make the sand fraction and those above 2 mm are distinguished as gravel.

Regardless of the differences between various classification systems, it can be observed that dried sludge from the AMWTP is composed of particles smaller than 1 mm, which are sand, silt and clay in different proportions. The finest fraction (clay) accounts for 14–20%, silt accounts for 28–60%, while sand accounts for 22–58%. It can be noted that sludge dried at high temperatures (80–120 °C) is characterized by a significantly higher content of the sand fraction (particle size greater than 0.05 mm). According to the textural triangle proposed by the USDA [44], dried WTS can be classified as sandy loam and silt loam (Figure 7).

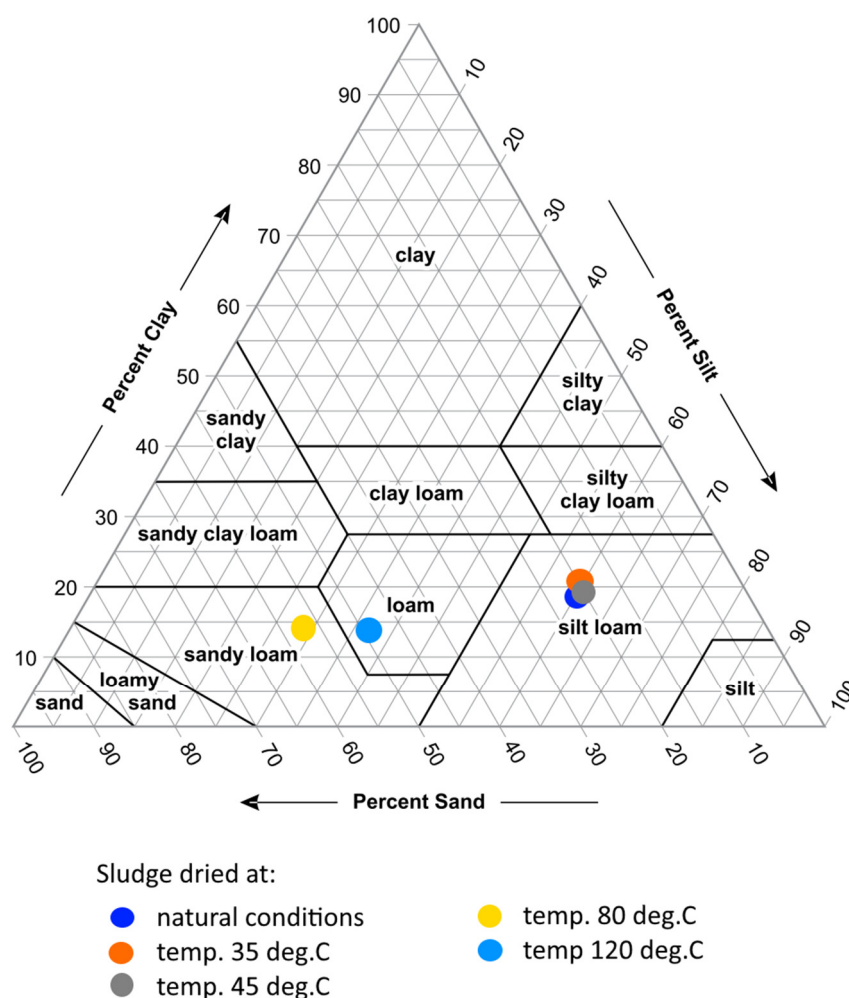


Figure 7. Texture classification of WTS after drying.

After drying, the sludge is a loose, low-strength, mostly finely dispersed material. Data on the chemical composition of dry sludge are presented in Table 4.

Table 4. Chemical composition of dried sludge.

Parameter	Minimum	Maximum	Average	Median	Percentile 25	Percentile 75
Aluminum, mg/kg	0.94	13.8	6.281	3.97	3.0	10.4575
Magnesium, mg/kg	0.89	2.4	1.731	1.77	1.66	2.0575
Phosphorus, mg/kg	0.21	0.36	0.28625	0.29	0.235	0.34
Sulfur, mg/kg	0.002	0.89	0.2466	0.13	0.027	0.405
Silicon, mg/kg	50.24	147.6	92.094	76.75	57.65	130.3
Potassium, mg/kg	1.72	5.51	3.972	4.28	3.0325	5.1975
Calcium, mg/kg	71.8	80.6	76.094	76.49	73.095	78.55
Titanium, mg/kg	0.09	1.2	0.6408	0.69	0.6175	0.78
Chromium, mg/L	0.001	0.9	0.336	0.074	0.04175	0.67
Manganese, mg/L	0.015	1.5	0.7783	0.885	0.57	0.96
Iron, mg/L	2	7.54	5.007	5.38	2.625	7.1625
Nickel, mg/L	0.9	4.4	2.074	1.6	1.345	2.655
Copper, mg/L	0.9	3.87	2.181	1.77	1.5525	3.1725
Zinc, mg/kg	0.048	1.55	0.7126	0.755	0.1025	1.2675
Bromine, mg/kg	0.001	0.041	0.01725	0.008	0.0055	0.0335
Strontium, mg/kg	0.08	1.53	0.853	0.975	0.285	1.29
Lead, mg/kg	0.85	1.7	1.207	1.205	0.95	1.375
Barium, mg/kg	0.001	0.021	0.004775	0.0026	0.001	0.00425
Indium, mg/kg	0.001	0.0021	0.001586	0.002	0.001	0.002

Data on the chemical composition of the dry sludge showed that the sludge contains a high concentration of aluminum—0.94–13.8 mg/kg, silicon—50.24–146.3 mg/kg, potassium—1.72–5.51 mg/kg, calcium—71.8–79.1 mg/kg, iron—2.0–7.54 mg/kg and nickel—0.9–4.4 mg/kg. At the same time, the content of barium (0.01–0.021 mg/kg), lead (0.85–1.7 mg/kg) and chromium (0.001–0.9 mg/kg) is relatively low and does not indicate the potential toxicity of the WTS [16]. The chemical composition of WTS from the Almaty Main Water Treatment Plant contributes to the further use of the sludge in various sectors of the economy. The introduction of such solutions, which are consistent with the sustainable development policy, including the 3R concept (recovery, recycling, reuse) [12], is particularly important for developing countries such as Kazakhstan, where sewage and sludge management is often based on outdated and environmentally unfavorable solutions [45].

4. Conclusions

The sludge from the Almaty Main Water Treatment Plant is currently disposed of directly into the municipal sewer system and conveyed to a wastewater treatment plant for further treatment. This is an economically rational, but certainly not sustainable, solution. Therefore, in the presented research, an attempt was made to investigate the susceptibility of WTS to thickening and mechanical dewatering and drying by various methods. Sludge processed in this way can be used in various industries, primarily as a substitute for natural soils in the production of construction materials.

Pilot-scale studies have shown that mechanical thickening and dewatering can reduce the sludge moisture content from 90 to 63%, which also results in a 73% reduction in the sludge volume relative to the initial raw sludge volume. This significantly reduces the cost of further sludge processing. Sludge drying allows a further reduction in the sludge moisture content to a value of 2.1–2.9%, resulting in a reduction in the sludge volume to about 10% of the volume of raw sludge.

Among the WTS drying methods studied, drying under natural conditions deserves special attention, giving the greatest reduction in moisture content, but also requiring the longest processing time. However, due to the potentially high reduction in the sludge moisture content after mechanical thickening and dewatering (a significant reduction in the volume of sludge to be dried and therefore less space required for the dryer) and the minimal investment needed, drying sludge under natural conditions may be the optimal

choice under climatic conditions similar to those in Almaty (high summer temperatures, high number of sunny days per year). It is obvious that, in most cases, WTS drying in natural conditions will not be sufficient due to the winter season; therefore, in our research, we also tested different variants of thermal drying, each of which showed a similarly high efficiency. This gives the possibility of using, e.g., hybrid methods, which are a combination of solar and thermal drying, but the choice of the final solution should take into account the specific local conditions, including the number of sunny days during the year, the availability of space for storing sludge, the possibility of using alternative energy sources, etc.

It is also worth mentioning that drying WTS in natural conditions is associated with a much smaller hazardous impact on the environment, including odor nuisance, than is the case with sludge from wastewater treatment plants. This is mainly due to the low content of organic matter in WTS, and consequently the low emission of volatile organic compounds, which are the main source of odors in sludge treatment facilities.

The obtained dried sludge, with its granulometric and chemical composition, resembles the sludges studied by other authors, especially in terms of WTS reuse in the construction industry. Importantly, the sludge from the AMWTP is not of a potentially toxic nature, which makes it possible to consider its use not only in the production of construction materials, but also its reuse in the environment, e.g., for soil reclamation.

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