KAPITEL 11 / *CHAPTER 11* [11]
SOME ISSUES CONCERNING THE SPECIFIC FEATURES OF TREATMENT AND UTILIZATION OF NATURAL AND WASTEWATER SLUDGE

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Introduction

In the process of treating natural waters of varying initial quality, a considerable diversity of sludge types is formed. This creates the necessity for systematization and classification of sludge to facilitate the selection of optimal treatment methods. During the purification of natural waters, sludge is generated due to the excessive content of dissolved substances, as well as from plankton and pollutants entering water sources with rainwater, meltwater, and wastewater.

In general, the sludge produced from water supplied for treatment at a water purification plant represents a complex, multicomponent spatial system with a highly developed surface area. Such a surface incorporates a combination of substances differing in origin, composition, and properties. The main components of sludge include the hydrolysis products of chemical reagents combined with mineral and organic substances, such as phyto- and zooplankton, microorganisms, as well as insoluble impurities introduced into the water together with the coagulant [1, 2, 10].

11.1 Chemical Reagents for Water Treatment

The most widely used chemical reagents for water treatment are mineral coagulants in the form of aluminum and iron salts, which results in significant amounts of hydrated Al and Fe oxides in the sludge, determining its properties [5, 7].

The oxide formed during water treatment with cationic flocculants is characterized by larger and stronger flakes compared to those formed using coagulants. Anionic flocculants are used in combination with mineral coagulants. The sludge

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produced in this process consists of impurities coagulated by Al and Fe hydroxides into flakes, which are then aggregated into larger clusters through the action of flocculant macroions.

The quantity of sludge generated depends on the quality of the treated water, the type of coagulants used, and the structural features of the facilities in which the sludge settles. Typically, sludge volume ranges from 0.1% to 1% of the treated water volume, and in some cases, it can reach up to 5% [8, 9].

Liquid wastes from water treatment plants contain high concentrations of impurities formed from pollutants characteristic of a specific water source (SiO_2, Fe_2O_3, CaO, MgO, metals, organic and biogenic substances of both anthropogenic and natural origin), as well as from reagents used in the water treatment process [2].

Table 1 presents the chemical composition and characteristics of the main groups of elements in water treatment plant sludge and their suitability for practical use.

Table 1 – Elemental Chemical Composition and Characteristics of Water Treatment Plant Sludge, %

<table>
<tr><td>SiO_2</td><td>Fe_2O_3</td><td>Al_2O_3</td><td>CaO</td><td>MgO</td><td>SO_3</td><td>P_2O_5</td><td>MnO</td><td>K_2O</td><td>Na_2O</td></tr>
<tr><td>45,5</td><td>8,9</td><td>24,7</td><td>11,2</td><td>3,5</td><td>2,3</td><td>0,1</td><td>1,0</td><td>2,0</td><td>0,9</td></tr>
<tr><td colspan="3" rowspan="2">1</td><td colspan="2" rowspan="2">2</td><td rowspan="2">3</td><td rowspan="2">4</td><td rowspan="2">5</td><td>6.1</td><td>6.2</td></tr>
<tr><td colspan="2">6</td></tr>
</table>

Notes:

1. Components of construction binding materials, fillers.

2. Components of construction binding materials; constituents for neutralizing acidic soils as alkaline agents.

3. Toxic components.

4. Components with fertilizer properties.

5. Components with oxidizing properties.

6. Components with alkaline properties.

Further drying of the sludge to constant weight at a temperature of 110 °C reduces its moisture content. Measurements of the samples showed that the sludge

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undergoes shrinkage deformations: during drying, the dimensions of gravel-sized samples decrease by 2–6 %.

According to sample analysis, the mineralogical composition of water treatment plant sludge is as follows:

- Quartz — 17–29 %
- Hydromica — 18–22 %
- Montmorillonite — 19–24 %
- Gypsum — 11–15 %
- Chlorite — 4.5–6 %
- Calcite — 2.2–3.6 %
- Colloidal, fine-dispersed organic substances — 21–28 %

The chemical composition of industrial wastewater sludge from the water treatment plant (as oxide percentages) is:

- CaO — 11.4 %
- Al_2O_3 — 21.1 %
- SiO_2 — 32.2 %
- P_2O_5 — 4.5 %
- SO_3 — 1.9 %
- MgO — 0.96 %.

11.2 Primary Methods of Sludge Dewatering

Dewatering (thickening) of wastewater sludge is the primary stage of its treatment and is intended to reduce its volume. The most commonly used methods are gravity and flotation thickening.

Gravity thickening is carried out in settling-thickening tanks, while flotation is performed in pressure flotation units. Centrifugal thickening using cyclones and centrifuges is also employed. Promising approaches include vibratory thickening, which involves filtering the sludge through filtering partitions or using vibratory devices immersed directly into the sludge.

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Sludge stabilization is used to decompose the biologically degradable portion of organic matter, preventing putrefaction during long-term storage in the open air (e.g., drying on sludge beds, use as agricultural fertilizers, etc.). Stabilization or mineralization of organic matter can be performed under anaerobic (methane fermentation) or aerobic conditions. For industrial wastewater sludge, aerobic stabilization is mainly applied—prolonged aeration in structures such as aeration tanks leads to the breakdown of the majority of biodegradable substances prone to decay. The period of aerobic stabilization at 20 °C is 8–11 days, with an oxygen demand of 0.7 kg per 1 kg of organic sludge.

Anaerobic digestion of sludge in methane tanks is carried out under mesophilic (t = 33 °C) or thermophilic (t = 53 °C) regimes, depending on the subsequent sludge treatment method [4, 5].

Dewatering of wastewater sludge aims to obtain sludge with a volumetric concentration of the polydisperse solid phase of up to 80%. Until recently, dewatering was mainly carried out by drying sludge on sludge beds. However, the low efficiency of this process, the scarcity of land in industrial areas, and air pollution have driven the development and application of more efficient dewatering methods: vacuum filtration, centrifugation, vibratory filtration, and thermal drying.

Thickening is the most common method for reducing sludge volume. During microbial activity, the amount of activated sludge continuously increases, generating excess activated sludge, which is separated from the recirculated sludge returned to aeration tanks. Given the high moisture content of excess activated sludge (up to 99.2–99.7 %), thickening is necessary [3, 10].

Typically, thickening is applied to excess activated sludge, in some cases to a mixture of activated sludge and raw sludge, and less frequently to raw sludge alone. Anaerobically digested and aerobically stabilized sludges can also be thickened. Since the moisture content of thickened sludge decreases significantly, the volume of facilities required for subsequent treatment is correspondingly reduced. The choice of an optimal thickening scheme is influenced not only by the type of thickener but also by the properties of the activated sludge.

Gravity Thickening

Reduction of sludge volume and moisture content by the gravity method is achieved through prolonged sedimentation. Thickening of excess activated sludge follows the principles of limited sedimentation of the suspension; the process typically lasts 9–12 hours, resulting in thickened sludge with a moisture content of approximately 97 %. During thickening, only free water is removed.

The degree of sludge thickening depends on both the residence time in the thickening zone and the pressure applied. Residence time is determined by the surface loading rate, expressed as kilograms of dry solids per square meter of water surface per day. For gravity thickeners, the typical surface loading rate is 20–30 $kg/m^2 \cdot day$ [2, 8].

Flotation Thickening

In flotation thickening, the release of water from the structural pores of activated sludge is intensified at the surface level. Air, introduced in the form of fine bubbles, interacts with the bound water on the surface of sludge particles, displacing it and converting it into a free state. The use of flotation allows achieving the same degree of sludge thickening in 10–20 minutes as would take 2 hours by gravity thickening.

Excess activated sludge is fed into the upper part of the flotation chamber, while the air-saturated working fluid is introduced at the bottom. Sludge and working fluid are distributed evenly across the chamber using radial distribution pipes with openings of 5–10 mm in diameter—pipes for sludge are installed from above, and pipes for working fluid from the side. The exit velocity of the fluid from the openings should be 0.7–1.0 m/s for sludge and 1.8–2.3 m/s for the working fluid.

Sludge water is removed from the bottom of the flotation chamber, while the sludge accumulating on the surface is periodically discharged (every 3–4 hours after reaching a moisture content of 94.5–95 %) into the sludge discharge trough using a spiral scraper.

Centrifugal Thickening

Centrifugal thickening of sludge suspensions is carried out in compact, high-capacity separators or centrifuges. The separation rate in this method is approximately 1000 times higher than in gravity thickening. Disc-stack separators are commonly

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used.

In separators with pulsed discharge, sludge is ejected from the drum when a moving element opens the discharge slots at the drum periphery. During full discharge, the feed of sludge to the separator is temporarily stopped, the drum discharge slots are opened, and the entire content—both sludge and liquid—is ejected into the receiving tank.

Use of disc-stack separators allows sludge to be thickened to a concentration of 40–60 g/dm³, with an average solids retention efficiency of 97 %. However, even with preliminary screening of sludge through sieves or drum screens, operation is often complicated due to frequent clogging of the separator nozzles [5-7].

11.3 Prospects for the Secondary Utilization of Thickened Sludge

A comparison of the chemical composition of water treatment sludge and natural ceramic clays indicates their chemical similarity and the correspondence of their crystalline structures. This is of crucial importance in the formation and firing of ceramic products and also affects their toxicity levels.

The content of toxic elements in the sludge was determined using chemical analysis of aqueous extracts from dried samples in a medium with pH 5.0–9.0. The results are presented in Table 2.

Table 2 – Content of Toxic Elements in Aqueous Extracts from Dried Sludge, mg/kg

Metal Composition in the Extract	Fe	Zn	Cu	Cr	Pb	Cd	Ni	Sr	Al
Aqueous extract at pH=5	0,15	2,9	2,1	9,4	0,05	0,005	5,8	115	8250
Aqueous extract at pH=7	0,4	0,03	0,1	0,25	0,03	0,003	0,3	14,4	0,1
Aqueous extract at pH=9	1	0,05	0,7	0,5	0,05	0,003	0,5	15,5	25,7

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Thus, water treatment plant sludge cannot be discharged into water bodies or retention ponds with natural bottoms without additional treatment due to its high toxicity. Losses during calcination of partially dried sludge from wash water range from 59–76 %, indicating a high content of organic impurities and bound water.

The obtained characteristics of contaminated wash water from water treatment plants further confirm the inadmissibility of its reuse in drinking water preparation processes due to the high concentration of toxic substances. Continuous reintroduction of organic and mineral contaminants into the mixing chamber of treatment facilities, combined with primary and secondary chlorination, leads to systemic accumulation of hazardous substances in the recirculation loop of the water treatment plant and exceeds permissible limits for drinking water quality [1, 4, 6].

11.4 Selection of Optimal Raw Material Composition Parameters for Preparing a Sludge–Clay Mixture

The selection of the optimal raw material composition for preparing a forming mixture (blended with ceramic mass) for the production of ceramic gravel was carried out based on the study of the composition and properties of industrial wastewater treatment plant (WWTP) sludge and the corresponding clay.

The sludge contains molecular water, capillary water, and a water-dispersed medium for clay and organic components. Water exerts a wedging effect on mineral grains: as the thickness of the water layer increases, it increasingly screens intermolecular forces, weakening the cohesion between grains. When pores are fully saturated with water, a second dispersing phase begins, menisci disappear, and the effect of capillary pressure ceases [4].

The addition of electrolytes to the sludge promotes the intensive breakdown of clay aggregates into elementary grains and helps achieve the required slip fluidity at minimal moisture content [1].

Requirements for fired products (gravel, crushed stone):

- High strength

- Resistance to water, acids, and alkalis
- Reduction of sludge toxicity through the incorporation of natural clay with suitable ceramic properties
- Mixture plasticity of at least 15
- Mixture suitable for forming gravel and crushed stone samples

Physico-chemical properties of the mixture:

- Melting temperature: 1140 °C
- Sintering temperature: 1060 °C
- Optimal firing temperature: 1020 °C
- Swelling temperature: 1160 °C
- Swelling coefficient: 2.1–3.0

Chemical composition of clay shale (% by mass):

- SiO_2 — 42.6–50.2
- Al_2O_3 — 16.0–17.1
- Fe_2O_3 — 5.3–6.9
- TiO_2 — 0.08–0.20
- Na_2O — 1.2–2.1
- CaO — 11.5–13.2
- MgO — 1.03–1.47
- K_2O — 2.62–2.83
- H_2O — 4.02–7.80
- P_2O_5 — 0.03–0.11
- SO_3 — 0.3–0.6

In the presence of organic matter and coal, filler grains are coated with a colloidal clay layer [2]. During heating, the organic components burn out, forming a porous glassy phase that cements the grain contact surfaces and creates a crystalline structure with high strength.

Formation process of the ceramic body with burnout additives:

- Clay mass contains aggregates with varying moisture, density, and hardness
- Burnout components form the intergranular structure and porosity of the

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products

The forming mixture includes quartz sand (0.05–0.5 mm fraction), recovered from the sand traps of the WWTP wash water recirculation tank. These samples of formed sludge, dried at 105 °C, were subjected to thermal treatment and tested for strength, toxicity, and water resistance [7].

11.5 Development of a Technology for Producing Ceramic Gravel Using Water Treatment Plant Sludge

The suitability of ceramic gravel as a filler for concrete products or as a construction material in road building is determined by its strength, resistance to water and aggressive environments, and environmental safety.

Factors affecting the strength of ceramic gravel include:

- Composition of the forming mixture
- Forming technology
- Thermal treatment regimes
- Cooling conditions of the products

One of the key parameters is the specific gas release, which depends on the decomposition and reduction of iron oxides, their interaction with organic impurities or additives, and chemically bound water in clay minerals. To form pores during firing of expanded clay, additives such as coal, diesel fuel, fuel oil, wood chips, pyrite cinders, peat, etc. are typically added to the clay. The gases generated in reduction reactions accumulate in the pores of the granules and participate in the expansion process.

After preparing the forming mixture, it was dried at 20 °C, and samples of ceramic gravel were produced in the form of spheres with a diameter of 15–25 mm. The mass of each sample was 20–30 g.

Forming mixture compositions:

- Group 1: 100 % industrial WWTP sludge
- Group 2: 50 % WWTP sludge + 50 % ceramic clay (filler)

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- Group 3: 50 % WWTP sludge + 25 % clay + 25 % quartz sand

Following the standard methodology for determining expanded clay strength, showed that after firing at 1100 °C, the gravel did not fracture under a compressive impact load of 33 kN/cm² [1].

The obtained gravel samples exhibit a cream color due to their iron content. The surface structure of the fired gravel samples is porous and rough, similar to many ceramic products. Ceramic gravel made from industrial wastewater sludge, after firing at 600 °C, showed a compressive strength of 4–7 kg/cm² [4].

Table 3 – Laboratory Test Results on the Strength of Ceramic Gravel Samples Made from Wash Water Sludge and Sludge–Clay Mixtures

Sludge Content in the Mixture, %	Clay Content in the Mixture, %	Quartz Sand Content in the Mixture, %	Firing Temperature, °C	Compressive Strength in Cylinder, kg/cm²	Grade (According to Expanded Clay Testing Methodology)
100	0	0	600	6,3	250(B)
50	50	0	600	4,0	200(B)
50	25	25	600	0,8	-
100	0	0	1120	33,1	550(A)
50	50	0	1120	14,8	350(A)
50	25	25	1120	2,3	-

Summary and conclusions

The sludge from water treatment plants is a complex multi-component system containing both mineral and organic substances. Its treatment and thickening are necessary to reduce volume and prepare it for further use.

Conditioning and stabilization of the sludge improve its physicochemical properties, reduce moisture content, and prepare it for dewatering or subsequent utilization.

The chemical and mineralogical composition of the sludge indicates its potential for use in the production of ceramic materials after appropriate thermal processing, which reduces toxicity and ensures the required strength of the products.

The production of ceramic gravel from a mixture of sludge and ceramic clay demonstrated satisfactory results in terms of strength, resistance to aqueous environments, and environmental safety, confirming the feasibility of its secondary use as a construction material.

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