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# STUDY OF THE PROCESS OF MECHANICAL DEWATERING OF LIQUID WASTE FROM MUNICIPAL WASTEWATER TREATMENT PLANTS IN SEDIMENTATION CENTRIFUGES

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**Abstract -** The article presents the results of studies of the process of mechanical dewatering of liquid waste from municipal wastewater treatment plants in Kharkiv, in particular, sediments formed at all stages of biological wastewater treatment. The city's wastewater has excessive concentrations of suspended solids (up to 400 mg/dm$^3$), biochemical oxygen demand (up to 250 mg/dm$^3$) and low transparency (1.9 cm), which complicates effective mechanical treatment. The paper analyses the operation of the main mechanical treatment facilities, including sand traps, primary and secondary settling tanks, as well as the sludge dewatering system, which includes a hydrocyclone GC-350 and an Ecomash SHS 511A-113 centrifuge. Industrial tests of the Dewatering Module have shown that continuous operation for 4-8 hours effectively removes coarse inclusions (stones, seeds, plant residues), and the concentration of suspended solids in the sludge is reduced during pretreatment. Laboratory studies have shown that conventional flocculation does not ensure proper deposition of activated sludge due to the presence of hydrophobic fat particles that cause flocs to float. A method of preliminary physical and chemical treatment with the addition of mineral carriers (clay, sand, anthracite) was proposed, which allows for dense, stable flocs that settle well. At the optimal dose of flocculant (0.06-3 kg/t) and dilution of sludge, an improvement in the deposition and quality of the fugate was observed. It is shown that the use of a model suspension with a carrier mineral and an optimal dose of flocculant allows achieving stable phase separation and reducing the moisture content of the sludge. The research results are useful for optimising the operation of wastewater treatment plants, increasing the efficiency of mechanical dewatering of sludge and reducing the volume of sludge masses for disposal or further processing.

**Keywords**: Environmental safety, Residual centrifuge, Wastewater, Excess activated sludge, flocculation, Treatment facilities.

## 1. Introduction

In today's conditions of rapid growth of wastewater volumes in cities, there is an urgent need for effective management of sludge generated in the process of wastewater treatment. In particular, in Kharkiv, about 6000 m$^3$ of municipal wastewater sludge with a moisture content of 96-98% is generated in aerotanks every day. Currently, it is dewatered on sludge sites with a total area of 126 hectares, which is half the required amount. Most of them are in unsatisfactory technical condition: the cards are overloaded, the drainage system is not functioning, and the expansion of the area for new sites is economically unreasonable.

In such circumstances, a reasonable solution is to introduce preliminary mechanical dewatering of sludge, in particular by using centrifuges.

This method is widely used abroad and can reduce the volume of sludge for further storage by 15-25 times. Given the general trend towards intensification of treatment processes at municipal and industrial wastewater treatment plants, the issue of efficient activated sludge processing is becoming particularly relevant.




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Activated sludge generated as a result of biological wastewater treatment is characterised by high humidity, significant volume, and the presence of both organic and inorganic impurities. Without proper treatment, its accumulation poses a serious environmental threat due to the possibility of secondary environmental pollution. Dewatering of activated sludge using centrifuges is one of the most effective physical and mechanical methods of preparing sludge for disposal. In addition to reducing the weight and volume, this opens up opportunities for further use of dewatered sludge as a secondary raw material.

## 2. Analysis of Literature Data and Problem Statement

Biological wastewater treatment is a leading technology due to its high efficiency in removing organic contaminants, ability to adapt to changes in the composition of incoming wastewater, environmental safety and process stability. However, this process results in the generation of significant volumes of excess activated sludge, which poses a serious environmental problem. Wastewater sludge can contain pathogens, heavy metals and organic pollutants that pose potential risks to the environment and human health if not properly disposed of [1, 10]. Due to the rapid development of industry and cities, the production of sewage sludge in the world is constantly growing, as is the need for sewage treatment plants [2], so the search for effective methods of dewatering and further processing of activated sludge is a critical area of modern research.

Particular attention in scientific research is paid to improving the efficiency of sludge dewatering, in particular by centrifugation. In [3, 4], the peculiarities of dewatering processes of fine suspensions were analysed and the influence of centrifugation parameters on the efficiency of moisture removal was studied. In particular, the efficiency of cleaning and dehydration of coal-containing sludge in centrifuges was considered, which allows us to draw certain parallels with the treatment of activated sludge [3]. Paper [4] highlights ways to intensify the dewatering process of polydisperse suspensions that can be applied to activated sludge of biological origin, taking into account its structural and rheological properties.

In general, dewatering of sewage sludge involves reducing the water content of the sludge and increasing the dry matter content. This is a key process for the post-treatment and further processing of sewage sludge [9].

Modern scientific research focuses on the low efficiency of activated sludge dewatering. The authors of studies [5, 8] note that centrifuges, belt filter presses, and rotary vacuum filters are not effective enough in treating sewage sludge with a high moisture content. In this regard, study [5] assessed the feasibility of introducing alternative dewatering methods using emulsions, ultrasound, and microwave irradiation in research or industrial plants. According to the results, the emulsion technology made it possible to reduce the moisture content in the sludge by up to 60%.

Another promising approach to improving the dewatering characteristics of activated sludge is preliminary chemical treatment, which is aimed at changing the physical and chemical properties of biomass. In the study [6], the authors analysed the effect of pretreatment of activated sludge with sulfuric acid and surfactant on exocellular polymers, dewatering capacity and sedimentation rate. The results showed that the efficiency of centrifugal dewatering improved with a decrease in sludge pH, especially with the additional use of surfactants.

In [7], the authors investigated the combined effect of hydrodynamic cavitation (HC) and the Fenton reaction. It was found that lowering the pH and reducing the sludge concentration improve dewatering, while the optimal parameters of flow rate and hydrogen peroxide concentration depend on the system configuration.

After the dewatering process, activated sludge still contains a large amount of organic matter, nutrients and micro-pollutants, so it needs to be further processed or disposed of.

In [11], the mechanisms of dewatering, methods of sludge conditioning (chemical, biological, physical and chemical) and their impact on the further use of sludge were analysed. The authors note that the efficiency of processing largely depends on preliminary conditioning, which affects not only the physical properties of the sludge but also its safety for reuse. Particular attention is paid to the possibilities of converting sludge into a source of energy, fertilisers, building materials, for example, in the production of bricks, cement or road surfaces, as well as a component for soil restoration [12].

Another promising area is the use of dewatered sludge as fertiliser. The authors of [13] studied the effect of ammonium sulphate treatment on improving sludge dewatering and further use as a source of nitrogen. The results showed a significant reduction in capillary suction time and specific filtration resistance. In addition, the treated sludge demonstrated the ability to stimulate seed germination, which confirms its suitability for agricultural use.

In addition to agricultural use, a promising area is the conversion of activated sludge into an energy source through thermal or biological conversion. In particular, the sludge can be subjected to anaerobic digestion to produce biogas or combustion to generate thermal energy, which reduces its volume

and neutralises residual harmful substances. According to the analysis of [11], it was found that the efficiency of sludge energy use largely depends on preliminary conditioning, in particular, dehydration, which reduces energy costs for drying.
Thus, dewatered activated sludge is a potentially valuable secondary resource that, if properly treated, can be effectively used in agriculture, energy and construction, helping to reduce the environmental burden on the environment and increase the efficiency of sewage treatment plants.
The aim of the research is to study the efficiency of dewatering of liquid wastes and sludges of municipal wastewater treatment plants in sedimentation centrifuges.

To achieve the goal it is necessary to:

- to carry out laboratory studies of composition and properties of liquid wastes of wastewater treatment plants;
- to carry out industrial tests of the liquid waste dewatering module and determine its efficiency on different sludges and sludges of wastewater treatment plants;
- to propose ways to intensify the quality of dewatering of excess activated sludge and to reduce the siltiness of centrifuge fugate.

## 3. Research Methodology

### 3.1. Analysis of the Existing Municipal Water Treatment Scheme

Municipal wastewater represents a mixture of domestic and industrial wastewater, with the calculated concentration of pollutants in the city of Kharkiv being 210 mg/dm$^3$ for suspended solids, 250 mg/dm$^3$ for total BOD, and a transparency of 1.9 cm.

The basic diagram of the existing wastewater treatment system in Kharkiv is shown in figure 1.

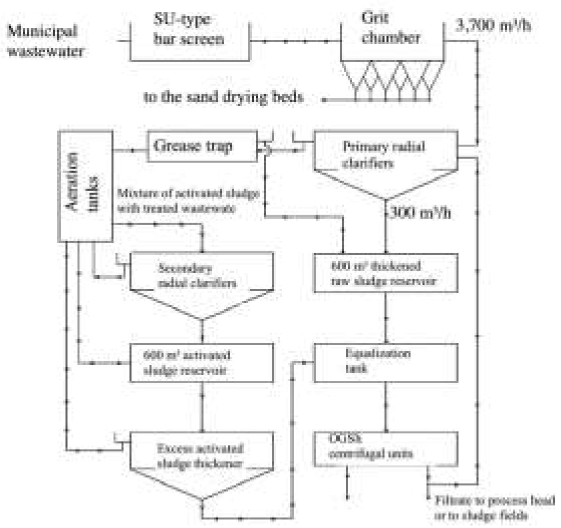


*Figure 1: Basic diagram of the existing treatment system*

The facilities intended for mechanical treatment of wastewater to remove large debris include *SU-type bar screens* with a spacing width of 5.5 mm. The screens are used to trap and remove large floating waste. The trapped debris is disinfected and transported to a special landfill.

To remove sand and various heavy mineral particles from the wastewater, the flow enters six sections of horizontal-type grit chambers with conical sumps. The throughput capacity of the grit chambers is 630,000 m$^3$/day.

The sediment retained in the grit chambers (mainly sand) is pumped by hydroelevators to sand drying beds. The design load on the sand beds is 3 m$^3$/m$^2$ per year, with a total area of 2,100 m$^2$.

After the grit chambers, the wastewater flows into primary radial clarifiers, consisting of four clarifiers with a diameter of 28 m (each with a volume of 1,969 m$^3$) and three clarifiers with a diameter of 40 m (each with a volume of 4,019 m$^3$). The purpose of the primary clarifiers is to remove suspended solids from the wastewater that settle by gravity or float to the surface. The throughput capacity of the primary clarifiers is 29,000 m$^3$/day. The design efficiency of the clarifiers is 40–50%. The amount of sludge generated during wastewater settling (with a moisture content of 94–96%) is 300–500 m$^3$/day. After treatment in the primary clarifiers, the total BOD ($BOD_{tot}$) is reduced to 131 mg/dm$^3$, and suspended solids to up to 100 mg/dm$^3$.

The sludge formed in the clarifiers is transported via a gravity sludge network to a raw sludge reservoir with a volume of 600 m$^3$. Floating substances are removed from the surface of the clarifiers using suspended devices installed on rotating bridges. These substances are collected into a hopper and then directed to a grease trap, from where they are further transported to the raw sludge reservoir.

After the primary clarifiers, the clarified wastewater flows into *aeration tanks*, where it is mixed with activated sludge and aerated. During this process, sorption and oxidation of organic substances occur, meaning biological treatment of the wastewater.

The throughput capacity of the aeration tanks is 83,000 m$^3$/day, with the entire treatment line designed for 300,000 m$^3$/day.

The air consumption for aeration is approximately 32,400–45,000 m$^3$/hour. The mixture of activated sludge and treated wastewater then enters secondary radial clarifiers, where the treated water is separated from the activated sludge, with a capacity of 75,000 m$^3$/day.

Activated sludge from the clarifiers is directed to the activated sludge reservoir (volume 600 m$^3$), while the treated effluent is discharged into the outlet channel and flows through a shielded collector into the Udy River.

The treated wastewater is disinfected in a special sealed mixing chamber, where chlorinated water is supplied via a dedicated pipeline from the chlorination facility. The active chlorine dose is 3 g/m$^3$ of wastewater.

Return activated sludge from the activated sludge reservoir is pumped back into the aeration tanks.

Excess activated sludge is sent to the *sludge thickener*, where it is thickened to a moisture content of 97.6–98.2%, and then flows by gravity to the raw sludge reservoir. The clarified water from the sludge thickener is directed to the aeration tanks of the old treatment line.

From the raw sludge reservoir, the sludge mixture is pumped into an equalization tank, then subjected to flocculation and mechanical dewatering using centrifuges. The filtrate generated during dewatering is pumped back to the head of the treatment facilities. The dewatered sludge is removed to designated storage sites.

## 3.2. Description of the Sludge Dewatering Module Operation

The study was conducted at the municipal wastewater treatment facilities of Kharkiv, where a modular installation was assembled (Fig. 2).

The sludge dewatering module for excess activated sludge consists of a technological chain of units that carry out the processes of dilution, mixing, classification, and dewatering of activated sludge.

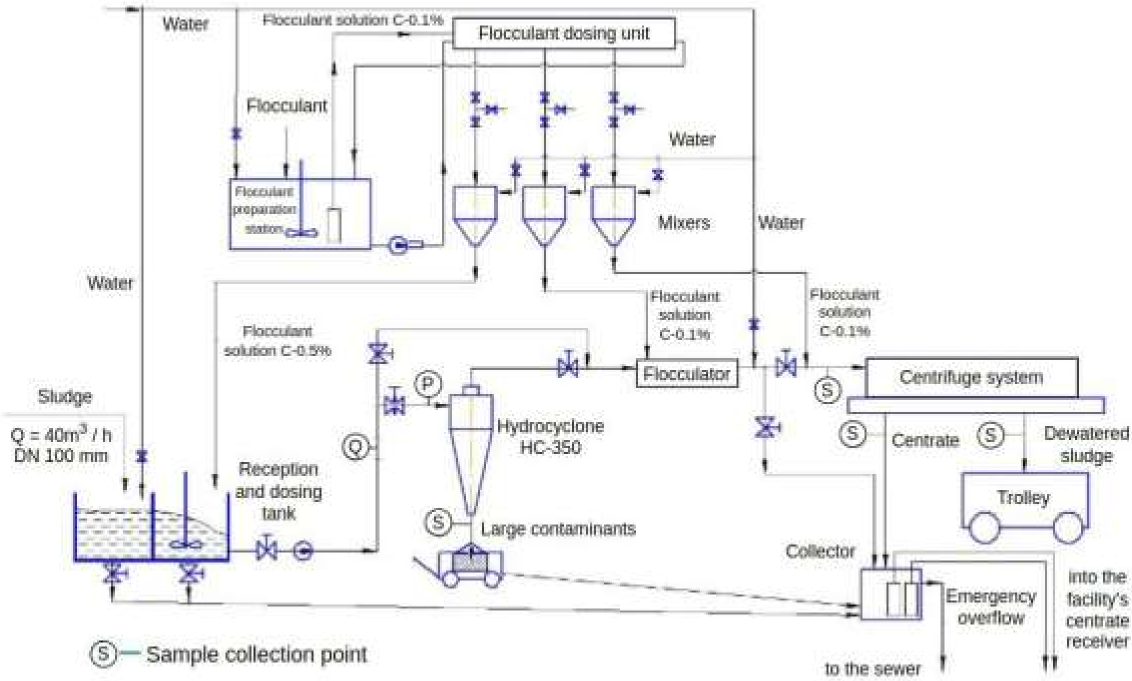


*Figure 2: Basic diagram of the module equipment chain*

To intensify the sludge settling process, aqueous solutions of flocculants based on polyacrylamide were also used (the type of flocculant was selected through laboratory testing).

A distinctive feature of the sludge dewatering technology is the use of technological laboratory tests that confirm the adequacy of sludge preparation for separation and subsequent dewatering by centrifugation.

The operation of the Sludge Dewatering Module is carried out in two modes:

1) Without the use of flocculant for sludge treatment:

– Sludge enters the receiving and dosing tank, from where it is pumped to the *HC-350 hydrocyclone*, where coarse sludge components are separated into a thickened fraction, and the clarified hydrocyclone effluent is directed to the centrifuge unit;

– The clarified product is dewatered in a sedimentation centrifuge; the centrifuge cake is transported to designated storage areas, and the centrifuge filtrate is sent to the filtrate reservoir at the facility.

2) With the use of flocculant for sludge treatment:

– From the flocculant preparation and dosing station, the working flocculant solution is fed into the receiving and dosing tank; then, with the hydrocyclone turned off, the flocculant-treated sludge is fed directly into the centrifuge unit.

The excess activated sludge dewatering module is equipped with standard industrial units that allow testing of the sludge dewatering processes and is used as a pilot plant with a capacity of up to 40 m$^3$/h.

# 4. Research Results

## 4.1 Results of the Laboratory Study of Wastewater Treatment Sludge

The excess activated sludge sampled at the outlet of the aeration tank contains an insignificant amount of fats and other contaminants (see Table 2) and traditionally settles slowly, forming loose flocs (Fig. 3a).

The results of the sedimentation kinetics of the raw sludge sample after 2 hours and 15 minutes of settling are presented in Fig. 3b. After settling, the raw sludge sample was diluted with water at a ratio of 1:8, and a cationic flocculant (Praestol) was added. The results of the separation of the raw sludge after dilution and treatment with the cationic flocculant are shown in Fig. 3c.

Separation of the thickened excess activated sludge into three phases was observed in laboratory glassware after adding a low dose (~2 kg/t) of cationic flocculant and diluting the sludge tenfold with water.

When the dose of the cationic flocculant exceeded 4 kg/t, the volume of the floated excess activated sludge increased up to 80%, while the clarified product remained turbid.

To assess the composition of contaminants during the treatment of municipal wastewater, samples of liquid waste were collected (Table 1).

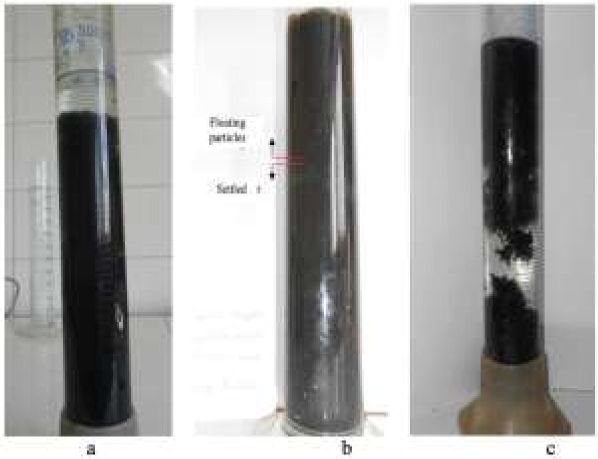


*Figure 3: Results of the settling test for a raw sludge sample from wastewater treatment facilities: a – settled excess activated sludge; b – after 2.5 hours of settling; c – raw sludge treated with a flocculant*

*Table 1. Results of the laboratory analysis of samples from municipal wastewater treatment facilities*

| № | Sample of Liquid Waste | Determined in the Sample | | | | |
|---|---|---|---|---|---|---|
| | | Suspended Solids, mg/dm$^3$ | COD, mg/dm$^3$ | Fats, mg/dm$^3$ | Phosphates, mg/dm$^3$ | Surfactants, mg/dm$^3$ |
| 1 | Feed to the Primary Settling Tank | 416 | 394 | 1,17 | 8,1 | 15,4 |
| 2 | Raw Sludge from the Primary Settling Tank | 28090 | 21230 | 524 | 180 | 12,3 |
| 3 | Clarified Product from the Primary Settling Tank | 328 | 311 | 0,34 | 15,4 | 1,92 |
| 4 | Excess Activated Sludge from Aeration Tanks | 1170 | 2740 | 4,65 | 96 | 1,49 |
| 5 | Thickened Excess Activated Sludge from Aeration Tanks | 7120 | 8980 | 362 | 210 | 1,87 |
| 6 | Treated Product from Aeration Tanks | 890 | 618 | 2,64 | - | - |
| 7 | Sludge Mixture | 21020 | 19490 | 961 | - | - |

The characteristics of sludge from municipal wastewater treatment facilities in Kharkiv are as follows.

The total content of suspended solids in 1 liter of wastewater entering the primary settling tank exceeds the design parameters – 400 mg/L (design value: 210 mg/L; maximum allowable value: 300 mg/L).

The concentration of synthetic surfactants, fats, and phosphates on the surfaces of suspended solids in the raw sludge from the primary settling tanks and in the thickened excess activated sludge is observed. This is explained, on the one hand, by the contact of surfactants with the developed surface area of suspended solids in raw sludge and thickened excess activated sludge, and on the other hand, by the presence of fine hydrophobic fat particles. As a result, at present, the raw sludge from the primary settling tank, the thickened excess activated sludge, and their mixtures represent three-phase systems: water, impurities heavier than water, and contaminants forming flocs lighter than water (Fig. 3).

The appearance of a significant amount of free fat after thickening of the excess activated sludge leads to its flotation, although before thickening the excess activated sludge traditionally settled in the form of flocs.

## 4.2 Results of Industrial Tests of the Sludge Dewatering Module for Municipal Wastewater, Equipped with the GC-350 Pressure Hydrocyclone and the Ecomash SHS 511A-113 Centrifugal Unit

Industrial tests of the sludge dewatering module, equipped with the GC-350 pressure hydrocyclone and based on the Ecomash SHS 511A-113 centrifugal unit, were conducted in operating cycles of 4 to 8 hours of continuous operation. Sludge samples fed for dewatering were analyzed in laboratory conditions.

Sludges with varying suspended solids content, ranging from 13 g/L to 49 g/L, were fed into the Dewatering Module and then into the GC-350 hydrocyclone for the retention of large particles.
During the tests, large stones (3–5 mm in diameter), peach and cherry pits, corn and sunflower seeds, plant fragments, and other materials were found in the thickened product of the hydrocyclone (Fig. 4).

The sand content in the thickened product of the GC-350 hydrocyclone increased twofold compared to the sand content at the inlet (Table 2).

*Figure 4: Large particles in the thickened product of the hydrocyclone*

To maintain a stable operating mode of the GC-350 hydrocyclone, a flow rate of 5±2 $m^3$/h was maintained in the thickened product line when the sludge feed rate to the hydrocyclone was approximately 25 $m^3$/h.

Additionally, a flow rate of 8±3 $m^3$/h was maintained in the thickened product line when the sludge feed rate to the hydrocyclone was approximately 40±7 $m^3$/h.

Typical performance indicators of the GC-350 hydrocyclone in the sludge dewatering module for municipal wastewater, according to laboratory test protocols of the sediments, are presented in Table 2. The clarified product from the GC-350 hydrocyclone was fed by gravity to the inlet of the Ecomash SHS 511A-113 centrifugal unit.

*Table 2. Typical performance indicators of the hydrocyclone*

| Type of Product | Feed Capacity of the Module, $m^3$/h | Product Characteristics | | | Characteristics of the Thickened Product from the GC-350 | | | | Characteristics of the Clarified Product from the GC-350 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Suspended Solids Content, g/L | Ash Content, % | Sand Content, % | Flow Rate in the Sand Nozzle, $m^3$/h | Suspended Solids Content, g/l | Moisture Content, % | Sand Content, % | Flow Rate of the Clarified Product from the Hydrocyclone, $m^3$/h | Suspended Solids Content in the Centrate, g/L | Ash Content, % | Sand Content, % |
| Mixture of Sludges | 17 | 20 | 23,4 | 0,6 | 6 | 21 | 97 | 1,1 | 11 | 16 | 27,8 | 0,5 |
| Raw Sludge | 28,6 | 32 | 26,7 | 1,8 | 6 | 34 | 96 | 3,5 | 22,6 | 32 | 27,2 | 1,6 |

Typical performance indicators of the Ecomash SHS 511A-113 centrifugal unit as part of the sludge dewatering module for municipal wastewater, according to laboratory test protocols of the sediments, are presented in Table 3.

*Table 3. Results of the study on the dewatering of liquid waste from municipal wastewater treatment facilities*

| № | Feed Capacity of the Module, m³/h | Product Characteristics | | | Centrifugal Unit Ecomash SHS 511A-113 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Suspended Solids Content in the Feed, g/L | , Ash Content, % | Sand Content, % | Rotor Speed, rpm | Relative Screw Speed, rpm | Flocculant Consumption, kg/t | Suspended Solids Content in the Centrate, g/L | Sludge Moisture Content, % | Sludge Ash Content, % |
| | Mixture of sludges | | | | | | | | | |
| 1 | 25 | 37,75 | 29,1 | 2,0 | 1800 | 19 | - | 29 | 70,6 | 40,9 |
| 2 | 12,7 | 7,75 | 24,8 | 1,0 | 1800 | 18 | - | 7,25 | 65 | 60,5 |
| 3 | 17 | 16 | 23,4 | 0,6 | 2000 | 21,6 | - | 14,25 | 66,4 | 56,4 |
| 4 | 17 | 21 | 25,8 | 0,8 | 2400 | 24 | - | 19,260 | 66,9 | 49,5 |
| | Raw Sludge | | | | | | | | | |
| 5 | 28,6 | 30,25 | 26,7 | 1,8 | 1500 | 15,1 | - | 18 | 67,2 | 45,4 |
| 6 | 16,5 | 20,5 | 29,2 | 1,9 | 2500 | 24 | - | 10,25 | 69,9 | 40,5 |
| 7 | 21 | 21,25 | 29,6 | 1,5 | 2100 | 17,9 | - | 15,5 | 66,1 | 45,5 |
| | Thickened Excess Activated Sludge | | | | | | | | | |
| 8 | 30 | 18,5 16 | 27,1 | 0,5 | 1500 | 15,1 | - | 14,25 13,672 | 68,7 | 45,3 |
| 9 | 19 | 24 | 25,4 | 0,5 | 2100 | 26 | - | 18,75 | 67,2 | 44,4 |
| 10 | 15,5 | 22,75 | 27,9 | 0,7 | 2500 | 24 | - | 15,53 | 65,8 | 43,2 |
| 11 | 15,5 | 23,67 | 27,7 | 0,9 | 2500 | 24 | - | 12,5 | 64,1 | 45,3 |
| 12 | 10 | 21 | 21,7 | 1,1 | 2500 | 23,8 | 8,99 | 12,2 | 70 | - |
| | Raw Sludge | | | | | | | | | |
| 13 | 33,5 | 13 | 23,8 | 3,7 | 2440 | 24 | - | 12,01 | 64,5 | 57,5 |
| 14 | 38,5 | 18 | 24,2 | 1,8 | 2100 | 23 | - | 13,06 | 59,9 | 60,1 |
| 15 | 41 | 24 | 29,7 | 4,0 | 1800 | 19 | - | 18,5 | 64,5 | 63,5 |
| 16 | 27 | 18 | 33,4 | 4,2 | 1800 | 19 | 11,46 | 14,25 | 63,2 | 63,3 |
| 17 | 16 | 14,25 | 30,5 | 3,7 | 1800 | 19 | 6,4 | 11,75 | 69,7 | 53,9 |
| 18 | 16 | 26,25 | 32,1 | 4,0 | 1800 | 19 | 4,6 | 17,25 | 69,7 | 40 |
| 19 | 14 | 49 | 38,2 | 1,9 | 1800 | 19 | 5,4 | 33 | 66,7 | 54,1 |
| | Mixture of Sludges | | | | | | | | | |
| 20 | 15 | 41 | 31,4 | 2,7 | 1800 | 19 | - | 25,11 | 61,7 | 58,3 |
| 21 | 15 | 42 | 33,9 | 2,4 | 1800 | 19 | 3,33 | 21,8 | 68,9 | 53,5 |
| 22 | 25 | 37 | 30,4 | 2,5 | 1800 | 19 | - | 30,398 | 59,2 | 56,1 |
| 23 | 32 | 41 | 32,52 | 2,3 | 1800 | 19 | - | 33,574 | 58,6 | 61,2 |
| 24 | 25 | 47 | 33,3 | 2,0 | 1800 | 19 | - | 27,8 | 62,3 | 46 |

## 4.3 Results of Laboratory Studies on Additional Treatment of Sludges and Centrates

To improve the efficiency of sludge centrifugation, laboratory work was carried out on additional physico-chemical treatment of centrates and sludges.

A model suspension with a mineral carrier was used (the gravitational settling rate of the main solid phase was 1 mm/s).

Clay, sand, and anthracite were used as the mineral carriers in the model suspension.

The concentration of the mineral carrier varied from 20 to 35 g/dm³.

The flocculant was used at a dosage ranging from 0.06 to 3 kg/t.

Sludges were also diluted with water in various proportions (Fig. 5).


*Figure 5: Samples of liquid waste after additional physicochemical treatment with model suspension and flocculant: a – excess activated sludge mixed with model suspension in a 3:1 ratio; b – centrifuge filtrate mixed with model suspension in a 1:1 ratio*

The centrate from the centrifuge after dewatering of raw sludge, the excess activated sludge, the thickened excess activated sludge, and the sludge mixture after the mentioned treatments resulted in the formation of strong and well-settling flocs, which is necessary for effective sludge centrifugation.

Thus, the use of the model suspension during the dewatering of raw sludge allowed obtaining a clarified product of the following quality (Fig. 5).

Treatment of centrifuge filtrate with a solid phase concentration of Cfi =25g/l after reagent-free dewatering of the sludge mixture resulted in the formation of strong and well-settling flocs (Table 4).

High settling rates $V_1$ and $V_2$ (after mixing the flocculated mixture) ensure successful separation in the centrifuge [14, 15]. The flocculant dosage was varied to assess the possibility of reducing costs. The selection of the mineral carrier primarily depends on the specific characteristics of the wastewater contaminants, as well as on the subsequent technology for the disposal of dewatered sludge.

The applied technology ensures the formation of strong flocs and reliable separation of filtrate and sludge in a two-phase centrifuge.

*Table 4. Results of the study on additional treatment of the filtrate*

| № | Model Suspension | Ratio of Filtrate: Mineral Carrier: Water | Suspended Solids Content in Suspension, g/dm³ | Flocculant Dosage TFK-3, kg/t | Flocculant Dosage TFK-18, kg/t | Settling Rate $V_1$, mm/s | Settling Rate $V_2$, mm/s |
|---|---|---|---|---|---|---|---|
| 1 | Anthracite + filtrate | 1:1 | 32 | - | 0,3 | 15 | 10 |
| 2 | Clay + filtrate | 1:1 | 30 | - | 0,3 | 20 | 12,5 |
| 3 | Sand + filtrate | 1:1 | 90 | - | 0,06 | 20-15 | 7-4 |
| 4 | Anthracite + filtrate + water | 1:0,5:2,5 | 11,75 | 1,1 | 2,1 | 9,3 | 4 |
| 5 | Clay + filtrate + water | 1:0,5:2,5 | 11,5 | 1,4 | 3,2 | 13 | 4 |

## 4.4 Discussion of Results

The results of industrial testing of the centrifugal unit Ecomash SHS 511A-113 are as follows. The centrifugal unit Ecomash SHS 511A-113 was tested on all types of sludge at a maximum feed rate of approximately 40 m³/h. In the reagent-free dewatering mode for various types of sludge, the moisture content of the centrifuge filtrate was 97–98%, and the moisture content of the sludge was 55–67%. The filtrate was contaminated with floating substances.

No stable correlation between the quality of sludge separation and the suspended solids content during centrifugation was observed. This confirms that the determining factor for effective sludge separation in the centrifuge is the preliminary chemical treatment of the sludge.

After treating raw sludge (or a sludge mixture) with the cationic flocculant Zetag 8185 and subsequent dewatering in the centrifugal unit (the hydrocyclone HC-350 was removed), the moisture content of the filtrate remained practically unchanged at 97–98%, which corresponds to laboratory test results. The filtrate was still contaminated with floating substances. The moisture content of the sludge ranged from 62% to 69%.

The flocculant dosage during the tests varied from 3.3 kg/t to 11.5 kg/t, while the sludge feed rate varied from 14 $m^3$/h to 32 $m^3$/h. The rotor drive load did not exceed 80%.

When testing the centrifugal unit Ecomash SHS 511A-113 on thickened excess activated sludge, similar observations were made:

– at a low flocculant dosage (<2 kg/t) during centrifugation of thickened excess activated sludge, the discharge of solid matter from the centrifuge and the release of clarified (relative to the feed) filtrate were observed;

– when the flocculant dosage exceeded 2 kg/t, the discharge of solid matter from the centrifuge was significantly reduced.

Laboratory studies were conducted on the additional physicochemical treatment of sludge to ensure the formation of strong flocs and effective sludge separation prior to centrifugation. Model suspensions with mineral carriers in the form of clay, sand, and anthracite were used in the experiments.

High-quality separation of sludge in the mixture with the model suspension was achieved when simultaneously treated with flocculants.

For the dewatering of sludge consisting of three phases, a two-stage treatment process is proposed, with two possible options:

Option 1:

– Reagent-free centrifugation of raw sludge (or a sludge mixture);

– Mixing of the filtrate with a mineral carrier and treatment with bioflocculants, followed by dewatering in a two-phase centrifuge.

Option 2:

– Reagent-free dewatering of raw sludge, subsequent mixing of the filtrate with a mineral carrier, and treatment with bioflocculants, followed by dewatering in a two-phase centrifuge;

Thickening of excess activated sludge by mixing it with a mineral carrier and treating it with mineral carriers in the form of microsands and flocculants at the inlet of the primary clarifier.

In this case, a two-phase raw sludge would be formed, and the effluent from the primary clarifiers would be additionally purified.

The use of a lamella clarifier to intensify the sedimentation process of the primary clarifier effluent would help reduce the load on aeration tanks.

The thickened excess activated sludge obtained after biological treatment would no longer form three-phase mixtures during flocculation, which would facilitate its mechanical dewatering by centrifugation.

– bioflocculants, with water discharge into a lamella clarifier (thin-layer settler);

– The thickened product from the clarifier is then fed into the two-phase centrifuge for dewatering.

A promising direction for further research is the testing of wastewater treatment technologies using

## 5. Conclusions

Industrial testing of the Sludge Dewatering Module, which includes the HC-350 pressure hydrocyclone and the centrifugal unit Ecomash SHS 511L-113, has established that during the dewatering of various types of sludge (raw sludge, thickened excess activated sludge, and their mixtures), the maximum feed capacity reached 40 $m^3$/h, and the moisture content of the centrifuge sludge ranged between 55% and 67%.

Currently, raw sludge from primary clarifiers, thickened excess activated sludge, and their mixtures represent three-phase systems: water, mechanical impurities heavier than water, and contaminants that form aggregates lighter than water.

In the traditional technology of chemical sludge treatment with flocculants (forming a three-phase system), using cationic flocculants from different manufacturers followed by dewatering in a two-phase centrifuge, it was found that the efficiency of suspended solids retention does not improve significantly, as one of the sludge phases is lighter than water.

Laboratory studies have selected options for additional physicochemical treatment of sludge prior to centrifugation by introducing an additional mineral component (clay, sand, anthracite).

The implementation of additional physicochemical treatment of sludge will allow for a reduction in the solid phase content of the centrifuge filtrate.

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