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DEVISING THE TECHNOLOGY FOR THICKENING AND DEHYDRATION OF ACTIVATED SLUDGE FROM MUNICIPAL TREATMENT PLANTS IN SEDIMENTATION CENTRIFUGES

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The object of this study is the process of thickening and dewatering excess activated sludge from municipal wastewater treatment plants in sedimentation centrifuges. The subject of the study is the conditions and factors that affect the efficiency of sludge dewatering, taking into account environmental safety, energy efficiency, and the possibility of reusing resources. The study is aimed at solving the problem of the efficiency and environmental safety of dewatering excess activated sludge.

The results of studies on the centrifugation of samples of excess and stabilized activated sludge in a laboratory centrifuge showed that effective separation into sediment and clarified liquid is achieved at a separation factor of 200–600 with the use of a flocculant. In an industrial centrifuge under a flow mode, the best results were obtained at a separation factor of 450 and a flow rate of 9.4 m³/h: the solid phase content in the thickened product was 12.8 g/l, at an input concentration of 4.2 g/l and the residual in the clarified liquid – 0.3 g/l.

The proposed scheme for thickening and dewatering sludge stabilizes the process and improves the quality of the product for further use or disposal. For effective dewatering, mixing the thickened sludge with thickened activated sludge is recommended due to the need for a mineral component. It has been established that thickening of activated sludge is possible using centrifuges in a weak centrifugal field (Fr = 200–600), with a cationic flocculant consumption of 5 kg/t. The second stage – dehydration – is implemented using sedimentation centrifuges.

The results could be used at municipal treatment plants to optimize the processes of thickening and dewatering of excess activated sludge, taking into account energy efficiency and environmental safety. The proposed centrifuge operating modes and the technological scheme enable process stability, reduce sludge volumes, and improve the quality of the final product for further use or disposal

Keywords: activated sludge, activated sludge dewatering, centrifugal units, thickening of excess sludge, environmental safety, fermented sludge, stabilized sludge

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1. Introduction

Modern wastewater treatment plants receive and process significant volumes of wastewater daily, resulting in the formation of a large amount of sludge – both fermented sludge from methane tanks and excess activated sludge. These sludges have high humidity, diverse composition, and unstable rheological properties, which significantly complicates their further dewatering, transportation, and disposal. In addition, the formation of sludge on such a scale is accompanied by an increased load on the infrastructure and creates risks of secondary environmental pollution.

According to data from [1], wastewater treatment plants in Europe annually process significant volumes of sludge, which confirms the relevance of the issue of its dewatering. A similar situation is observed at the Bortnytsia Aeration Station (BAS) (Ukraine) where significant volumes of excess activated sludge and fermented sludge are formed.

For example, in France, according to study [1], as of 2017, more than 800 thousand tons of dry sludge residue were subject to treatment per year, mainly from treatment plants using the activated sludge method. In particular, it was noted that about 80% of the volume of sludge is subjected to mechanical dewatering (using centrifuges, belt filters, and chamber filter presses), after which, depending on the further use (agricultural use, incineration, composting), additional treatment is carried out. The survey conducted as part of that study showed that the efficiency of mechanical dewatering plays a key role in reducing the costs of transportation and storage of sludge, and also directly affects the choice of the route for further disposal. It is noted that under conditions of decentralized sludge management, the availability of flexible, modular solutions that can adapt to local characteristics is important – this is exactly the approach demonstrated by the BAS pilot module. In addition, automated sediment moisture control systems are actively used in France, which enables rational dosing of reagents and stability of the dehydration process under conditions of variable sediment composition.

Modern sludge dewatering technologies are mainly developed for sludge with homogeneous physicochemical properties [2, 3]. For example, at BAS in Kyiv, sludge is transported by pipelines for a distance of more than 7 km, undergoing hydrodynamic changes, which significantly affects its structure. At the same time, the influence of hydrodynamic factors during sludge transportation remains insufficiently studied, which opens up prospects for further scientific work aimed at optimizing the structure of sludge and increasing the efficiency of its processing.

In particular, excess activated sludge has a low ability to mechanical dewatering due to the lack of a mineral framework, while fermented sludge contains components that promote floc formation and increase the efficiency of sedimentation. This necessitates the mixing of different types of sludge fractions before dehydration and the use of specialized reagents – mainly cationic flocculants. The accumulation, partial dehydration, and compaction of sludge is carried out at sludge sites, which occupy significant areas, and this process requires a lot of time. In addition, the handling of this waste can cause secondary pollution of the environment with sludge decomposition products, in particular odorants [4, 5]. Modern directions of processing excess sludge, for example, into fertilizers, are complicated by the lack of effective methods of its dehydration. A promising method of dehydration is the use of industrial centrifuges, the stability of which depends on the design features, operating modes, characteristics, and composition of the feed and other factors [2, 6]. Therefore, it is difficult to predict without additional research the efficiency of centrifugal units in the dehydration of excess activated sludge from municipal treatment plants.

To overcome these limitations, modern research focuses on the development of innovative technologies. These technologies combine mechanical dewatering with preliminary chemical or biological treatment of sludge, which makes it possible to increase the efficiency of centrifugation and process stability. In particular, the use of cationic flocculants, as noted in [2], contributes to the formation of stable flocs, which facilitate the separation of solid and liquid phases in centrifuges.

Analysis of modern approaches to reducing the amount and improving the quality of sludge in wastewater treatment processes reveals that OSA (oxic-settling-anaerobic) technology makes it possible to significantly minimize the formation of excess sludge by optimizing biological processes, although the impact of this method on the physicochemical properties of sludge is not described in detail in available sources [7].

Thus, research into the efficiency of sludge thickening and dewatering in industrial centrifuges is relevant in view of the need to reduce the man-made burden on the environment, optimize reagent consumption, and increase the efficiency of sludge processing at treatment plants.

2. Literature review and problem statement

One of the main challenges in wastewater treatment is the effective dewatering of excess activated sludge and fermented sludge, which are formed in large volumes at urban wastewater treatment plants. Activated sludge is an aerobic flocculated biomass consisting of microorganisms, insoluble organic matter, and weightless particles. It is formed during the aeration treatment process, where biological oxidation of pollutants is ensured, and the formed flocs are subsequently deposited in secondary settling tanks [1]. However, an urgent problem is to improve the efficiency of dewatering excess activated sludge and fermented sludge since their significant volumes complicate further disposal and processing.

In [8], seasonal variability in activated sludge biomass density and its effect on sedimentation were demonstrated using metagenomic analysis. The advantage is the use of modern methods for analyzing microbial composition, which provides a deep understanding of seasonal fluctuations. However, the work does not propose mechanisms for stabilizing biomass density, which remains an unsolved problem.

Sludges are a complex object for mechanical dewatering due to their high moisture content, colloidal structure, and significant compositional variability. This necessitates the need for complex technological solutions. They must take into account the physicochemical properties of the sediments and enable stable operation of the equipment with minimal energy consumption.

Flocculation is a key step that enables the formation of structured flocs suitable for effective extraction during centrifugation. Work [9] shows that optimizing the dosage of reagents increases efficiency but does not consider how fluctuations in the composition of the sludge affect these optimal parameters.

In [10], a two-stage thickening and dewatering technology was proposed, which provides extraction of up to 97% of the solid phase. The advantage is high efficiency, but the disadvantage is ignoring the influence of mixed sludges with different rheological properties; this aspect is planned to be investigated in our work by adapting the centrifugation modes.

In [11], the mechanisms of wastewater sludge dewatering were analyzed, focusing on the influence of chemical conditioning (flocculants, acid-base treatment) and thermal treatment. The study emphasizes that thermal methods significantly increase dehydration due to the release of bound water but require optimization of energy consumption. The disadvantage of the method is insufficient attention to practical methods for reducing energy consumption, which remains an unsolved problem.

Study [12] considers alternative strategies for dewatering excess activated sludge, including the addition of drinking water sludge, the use of constructed wetlands, and adaptive technologies for small-scale treatment plants. However, the authors note that most of the proposed solutions are either energy-intensive or limited in scale, which makes their use at large municipal treatment plants difficult. Thus, the study does not address the issue of devising energy-efficient and scalable technology for dewatering activated sludge, which necessitates laboratory and industrial centrifugation experiments to determine the optimal operating conditions.

In addition, attention focuses on the microbiological risks associated with improper sludge disposal [13]. Even after mechanical dewatering, sludge deposits can remain a source of pathogens, which requires the integration of hygienic stabilization processes before final settling or disposal.

In [14], attention is on mechanical dewatering of sludge in centrifuges, but the issues of optimizing operating modes and reducing energy consumption remain unresolved. In [15], the effect of oxygen regime in aerotanks-dislepsers was investigated, but further treatment of the formed sludge was not considered. In [16], attention is on biological activation of microorganisms to improve the efficiency of treatment, although the problem of dewatering excess sludge remains open. In [17], the use of lime was proposed to increase the dewaterability of industrial sludge, but the method has limitations in terms of versatility and environmental consequences. Study [18] addresses the chemical treatment of sludge for deep dewatering, but the risks of the influence of residual reagents on the operation of treatment plants were identified. In [19], the prospects for water reuse by dewatering mineral tailings are considered, but the issue of integrating such solutions into urban water treatment systems remains unresolved.

Thus, there are the following unresolved aspects of modern research in the area of dewatering excess activated sludge and fermented sludge at large treatment plants:

– insufficient number of applied studies on the behavior of mixed sludges (fermented sludge and stabilized activated sludge) in two-stage mechanical dewatering processes;

– lack of systematic analysis into the influence of the composition of sludge mixtures, their rheological properties, and flocculation modes on the efficiency of sedimentation centrifuges;

– limited number of solutions for automated regulation of flocculant dosage and sludge moisture under variable load conditions on pilot or full-scale modules;

– lack of proven modular technologies capable of adapting to the specificity of the operation at large urban treatment plants.

Given the above, there is a need to devise and test adaptive technological solutions. They should enable effective dewatering of mixed sludges at minimal energy and reagent consumption. It is also important to achieve stable operation of centrifuges. This would allow for the disposal or reuse of treated water. Conducting such a comprehensive study based on a pilot module could allow us to improve existing technologies and formulate scientifically sound recommendations for large-scale implementation.

3. The aim and objectives of the study

The purpose of our study is to determine the possibility of effective thickening and dewatering of excess activated sludge and fermented sludge in industrial centrifuges. The attention is paid to determining the optimal sludge mixing modes, centrifugation parameters and process stability with variable sludge composition in order to enable energy efficiency, reduce cake moisture, save reagents, and reduce environmental impact.

To achieve this goal, the following tasks had to be solved:

– to assess the efficiency of separating fermented sludge and excess activated sludge into a liquid phase and sludge in a laboratory centrifuge;

– to investigate the performance and stability of an industrial sedimentation centrifuge under different technological modes;

– to formulate practical recommendations for designing a technological module for dewatering excess activated sludge at municipal wastewater treatment plants.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of our study is the process of thickening and dewatering excess activated sludge from municipal wastewater treatment plants in sedimentation centrifuges. The hypothesis of the research assumes the possibility of effective thickening and dewatering of excess activated sludge from municipal wastewater treatment plants in the field of centrifugal forces under laboratory and industrial conditions to design a modular installation.

The study assumes that the physicochemical properties of excess activated sludge from different municipal wastewater treatment plants are similar and can be generalized; the results of laboratory experiments are extrapolated to industrial conditions taking into account the scaling of processes. It was also believed that the use of centrifugal forces is a determining factor in the efficiency of sludge thickening and dewatering.

Among the simplifications, it was accepted that the impact of foreign impurities (fats, polymers, microplastics) is insignificant; energy costs and equipment wear were estimated in a generalized manner without a detailed technical and economic analysis; changes in the microbiological composition of the sludge during the treatment process were not considered.

4. 2. Methodology for studying the degree of thickening of excess sludge in a laboratory centrifuge

We used samples of BAS activated sludge from aeration tanks and stabilized activated sludge from a digester card. During the study, the samples were grouted in a laboratory centrifuge and the ratio of the volumes of sludge and clarified liquid, as well as the moisture content of the sludge, was determined. When using a flocculant, a cationic flocculant was added to the sample before grouting and mixed. During the research, the samples were placed in plastic transparent cups with a volume of 10 ml of a laboratory centrifuge TsLN-2 and turned on at different speeds, which corresponded to the separation factor from 0 to 1000. After the rotor accelerated and reached the required speed, the centrifuge was turned off, the volume of clarified liquid was measured, and the moisture content of the sediment was determined by drying at a temperature of 105°C to constant weight according to the methodology MVV No. 081/12-0785-11 [20]. The dry residue was weighed, and the moisture content was determined as the ratio of the mass of the dry residue to the mass of evaporated water.

4. 3. Research methodology for the degree of thickening of excess sludge in an industrial centrifuge

To determine the efficiency of the centrifuge for thickening and dewatering activated sludge, activated sludge from the treatment plants in Kharkiv, selected during previous studies [14], was used. The scheme of the industrial experiment in an industrial centrifuge is shown in Fig. 1. Excess activated sludge was pumped into the receiving tank, and then by gravity it was fed into the Ecomash SHS 521AS-113 centrifuge (LLC "Scientific and Technological Center "Ecomash", Ukraine). When using a flocculant, a flocculant was also added to the receiving tank, which was mixed with excess activated sludge in the tank corridors (Fig. 1, section A). A sampler was installed in front of the centrifuge to determine the concentration of the solid phase and its humidity in the centrifuge feed. Power consumption was regulated by adjusting the pump and shut-off valves before the centrifuge.

The pumps were pre-adjusted, the shut-off valves were adjusted, and the centrifuge operation was checked on water. Then, after adjusting the modes and emptying the centrifuge rotor, excess activated sludge (EAS) was fed. For the experiment, the feed of the working solution of the flocculant CR8 with a concentration of 0.1% in the amount of 5 kg/t of dry matter was set.

To enable uniform mixing of the flocculant with activated sludge, internal guide corridors of the receiving tank were used. After mixing, the treated excess activated sludge (EAS) entered the working zone of the centrifuge, where it was further dehydrated.

The Ecomash SHS 521AS-113 centrifuge operated under selected grouting modes, which were previously determined on the basis of laboratory studies. Process stability was monitored by periodic sampling of the solid residue and grout at the outlet of the equipment. The main indicators of dehydration efficiency were moisture content of the solid residue, degree of water removal, energy consumption, and process stability over time.

At the final stage of the experiment, the obtained sediment was analyzed for further disposal or use, in particular as a secondary resource (for example, in agriculture or as fuel); we also assessed the grout quality in accordance with regulatory requirements for the discharge of treated water.

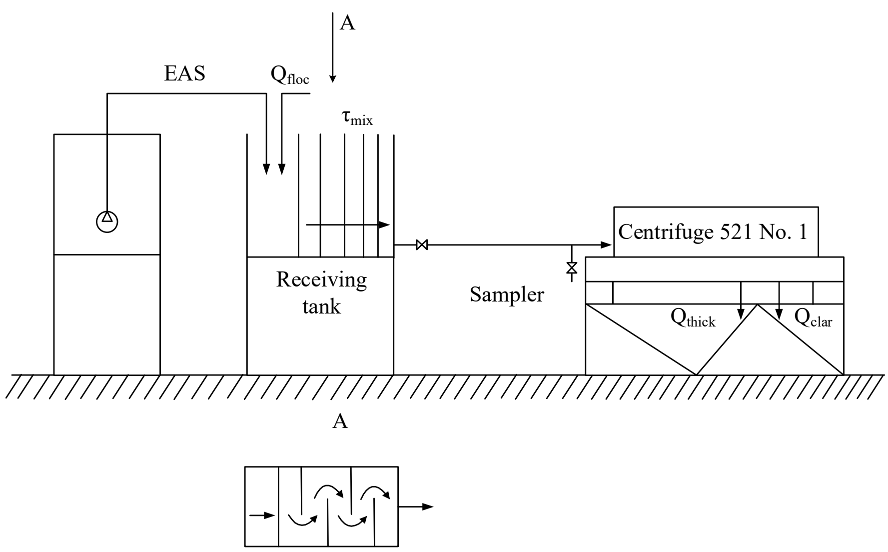

Fig. 1. Scheme of tests for thickening excess activated sludge in an industrial centrifuge

During our tests, the following indicators were determined:

– the amount of activated sludge in the feed;

– the amount of thickened product and its moisture content;

– the amount of clarified liquid and the content of activated sludge in it.

The amount of excess activated sludge in the feed and fugate, as well as the moisture content of the centrifuge sediment, was determined by drying liquid samples at a temperature of 105°C to constant weight according to the methodology MVV No. 081/12-0785-11 [20]. Quantitative indicators of liquid flow were measured by actual volume and flowmeter readings.

5. Research on the efficiency of separation and dehydration of excess activated sludge

5. 1. Results of research on the efficiency of separation and dehydration of excess activated sludge in a laboratory centrifuge

The results of grouting in a beaker centrifuge of samples of excess activated sludge (EAS) from aeration tanks with a solid phase concentration of 5 g/l by dry weight under a reagent-free mode and with the addition of a flocculant are given in Table 1 and Fig. 2.

The curves shown in Fig. 2 are a 3rd order polynomial and are described by the following equations for sludge dewatering processes with the use of flocculant (y_1) and without the use of flocculant (y_2):

$$y_1 = 99.5944 - 0.0142x + 2.3717\cdot10^{-5}x^2 - 1.2722\cdot10^{-8}x^3; \quad (1)$$

$$y_2 = 99.3217 - 0.0103x + 1.7164\cdot10^{-5}x^2 - 9.8844\cdot10^{-9}x^3; \quad (2)$$

where y_1 and y_2 are, respectively, the humidity of activated sludge during dehydration with and without the use of flocculant, %; x is the value of separation factor.

Analysis of Table 1 reveals that the main separation of the sample into clarified liquids is carried out at a separation factor of approximately 700, and when it is increased to 1000, only a slight compaction of the sediment occurs (a decrease in volume from 14 to 12%). The change in sediment humidity also occurs most intensively before the centrifuge is accelerated to a separation factor of 600–700. At the same time, the total humidity changes to 96.8%. The use of a flocculant intensifies the separation of the sample at low speeds in the separation factor range of 200–700. With an increase in the separation factor to 1000, no differences are observed compared to flocculated sludge and without the use of a flocculant.

The results of grouting in a beaker centrifuge of samples of stabilized EAS with a solid phase concentration of 14 g/l under the reagent-free mode and with the addition of a flocculant are given in Table 2 and Fig. 3.

Table 1

Results of grouting samples of excess activated sludge from aeration tanks

Grouting mode		Separation results			
Separation factor (Fr)	Time, s	Volume of clarified product, %	Volume of condensed product, %	Volume of clarified product, %	Volume of condensed product, %
		Flocculant-free		With flocculant	
0	0	0	100	0	100
65	69	60	40	70	30
100	80	74	26	70	30
200	118	82	18	80	20
500	156	86	14	82	18
700	174	86	14	86	14
1000	200	88	12	88	12

Note: the separation factor (Fr) is a dimensionless quantity that characterizes the efficiency of centrifugation and is determined by the ratio of centrifugal force to gravitational force [6, 21].

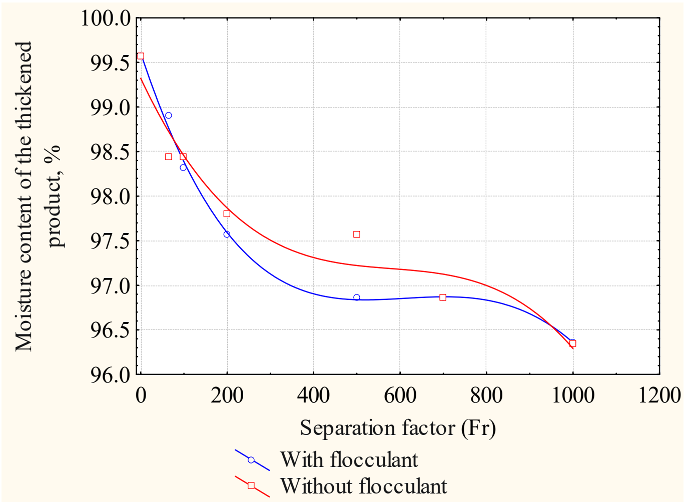

Fig. 2. Dependence of moisture content of the thickened product of excess activated sludge on the separation factor in a laboratory centrifuge

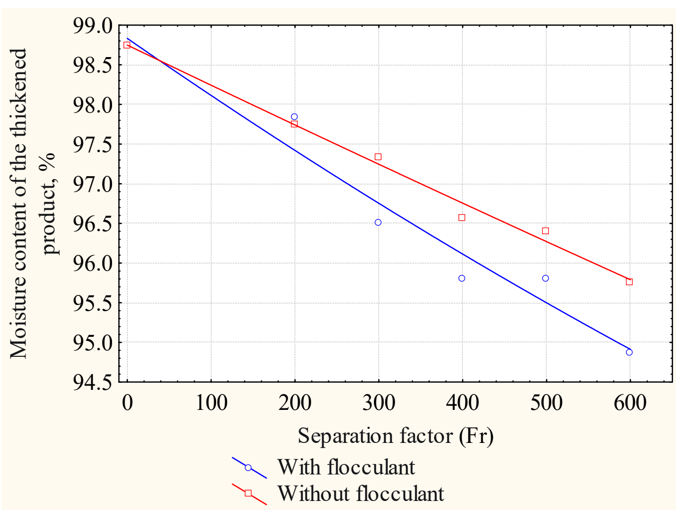

Fig. 3. Dependence of moisture content of the thickened product of stabilized excess activated sludge on the separation factor in a laboratory centrifuge

Table 2

Results of grouting samples of stabilized excess activated sludge from aeration tanks

Grouting mode		Separation results			
Separation factor (Fr)	Time, s	Volume of clarified product, %	Volume of condensed product, %	Volume of clarified product, %	Volume of condensed product, %
		Flocculant-free		With flocculant	
0	0	0	100	0	100
200	122	36	64	42	58
300	120	46	54	64	36
400	140	58	42	70	30
500	158	60	40	70	30
600	166	66	34	75.5	24.5

The approximating curves shown in Fig. 3 follow a linear dependence and are described by the following equations for the processes of dewatering stabilized sludge with the use of flocculant (y_1) and without the use of flocculant (y_2):

$$y_1 = 98.7664 - 0.0065 \cdot x; \quad (3)$$

$$y_2 = 98.735 - 0.0049 \cdot x; \quad (4)$$

where y_1 and y_2 are, respectively, the moisture content of activated sludge during dehydration with and without the use of flocculant, %; x is the value of the separation factor.

The coefficients of determination in equations (3) and (4) are, respectively, $R^2 = 0.9895$ and $R^2 = 0.9571$.

Analysis of the results in Table 2 reveals that stabilized activated sludge during fermentation is partially mineralized and better separated both without the use of flocculant up to 34% by volume and with the use of flocculant up to 24.5%. Flocculated stabilized sludge gives off moisture better, which is also noticeable in Fig. 3. An increase in the separation factor above 600–700 did not lead to a significant decrease in moisture.

5. 2. Results of studies on the efficiency of separation and dehydration of excess activated sludge in an industrial centrifuge under a co-current mode

The results of testing the Ecomash SHS 521 AS-113 centrifuge under a co-current mode with the supply of activated sludge based on the research scheme shown in Fig. 1 are given in Tables 3, 4. In tests 1–10, a flocculant was used in an amount of 5 kg/t, in tests 11–12, no flocculant was added.

Table 3

Results of EAS separation in the Ecomash SHS 521 AS-113 centrifuge

No. of order	Centrifuge operating mode		Centrifuge power, m^3/hour	Separation results, m^3/hour	
	Rotor speed, rpm	Fr		Thickened product, Q_{thick}, m^3/hour	Clarified fugate, Q_{clar}, m^3/hour
1	800	199.11	4.9	0.878	3.821
2	800	199.11	4.9	0.878	3.821
3	800	199.11	9.4	0.413	9.1
4	800	199.11	9.4	0.413	9.1
5	1200	448	19.2	2.2	16.7
6	1200	448	9.4	2.1	7.1
7	1200	448	9.4	2.1	7.1
8	1200	448	9.4	2.1	7.1
9	1300	525.78	12.7	2.7	9.4
10	1300	525.78	8.5	4.9	3.2
11	1300	525.78	9.4	2.2	7.2
12	1300	525.78	9.4	2.2	7.2

Analysis of the results in Tables 3 and 4 reveals that the most effective separation of EAS was observed in experiment 7, in which the amount of solid phase in the thickened product was 12.8 g/l at an input concentration of solid phase of 4.2 g/l with a solid phase content in the clarified liquid of 0.3 g/l. In addition, samples 6, 8, and 10 are characterized by fairly stable results in terms of the solid phase content in the thickened product and clarified liquid.

Table 4

Dry matter content (*C*) and total moisture (*W*) of liquid samples

No. of entry	Sampling time from the moment of feeding EAS into the centrifuge, s	In the centrifuge feed		In a condensed product		In clarified fugate	
		C, g/l	*W*, %	*C*, g/l	*W*, %	*C*, g/l	*W*, %
1	18	0.78	99.92	2.1	99.79	0.48	99.95
2	30	1.02	99.9	3.5	99.65	0.45	99.95
3	18	0.51	99.95	1.4	99.86	0.44	99.96
4	30	0.81	99.92	3.8	99.62	0.62	99.94
5	30	4.4	99.56	4.2	99.58	3.1	99.69
6	60	4.1	99.59	5.7	99.43	0.1	99.99
7	80	4.2	99.58	12.8	98.72	0.3	99.97
8	105	5.5	99.45	13.6	98.64	1.4	99.86
9	90	11.9	98.81	16.8	98.32	6.8	99.32
10	155	9.1	99.09	12.8	98.72	0.8	98.92
11	132	9.4	99.06	13.1	98.69	7.5	99.25
12	172	9.9	99.01	14.0	98.6	7.9	99.21

5. 3. Design of a technological module for cleaning and dewatering excess activated sludge for municipal wastewater treatment plants

Based on the results of our research, a technological scheme for thickening and dewatering activated sludge for municipal wastewater treatment plants at BAS was built (Fig. 4), as well as a module model (Fig. 5).

At BAS, the amount of compacted stabilized excess activated sludge exceeds the amount of fermented sludge by 1.5 times. To create satisfactory conditions for mixing sludge before dewatering in the pilot Module, additional thickening of sludge is provided by the Ecomash SHS 600 A-113 centrifuge, which operates in relatively weak centrifugal fields ($Fr \sim 200–600$, and therefore with low energy consumption). The thickening centrifuge is operated continuously with a capacity of 50 to 100 m^3/hour (1200–2400 m^3/day). To enable high-quality thickening and clarification of sludge in the centrifuge, a cationic bio flocculant is used with a flow rate of 5 kg/t. Optimization of the flocculant flow rate is carried out by a sludge moisture sensor. The clarified water after the thickening centrifuge can be sent to the bio pond, and the thickened sludge is stored in a storage tank ($V \sim 600$ m^3), from which it is fed at a flow rate of 25–50 m^3/hour to be mixed with fermented sludge and dewatered.

Dewatering of the sludge mixture or fermented sludge is carried out by two Ecomash SHS 540/490 A-113 sedimentation centrifuges with a capacity of 25–40 m^3/hour each. The proportions of sludge mixing are selected based on the results of technology debugging.

Before feeding sludge to centrifuges, drum screens BS 1308-4 are used, which categorize the centrifuge feed, separating large foreign objects and partially fibrous structures, thereby forming a super-screen product.

Using a 2-stage sludge dewatering technology (thickening and actual dehydration) according to the design qualitative and quantitative scheme (regulations), up to 1200 m^3/day can be processed at the thickening stage, of which approximately 600 m^3/day is sent for dehydration together with 600 m^3/day of fermented sludge.

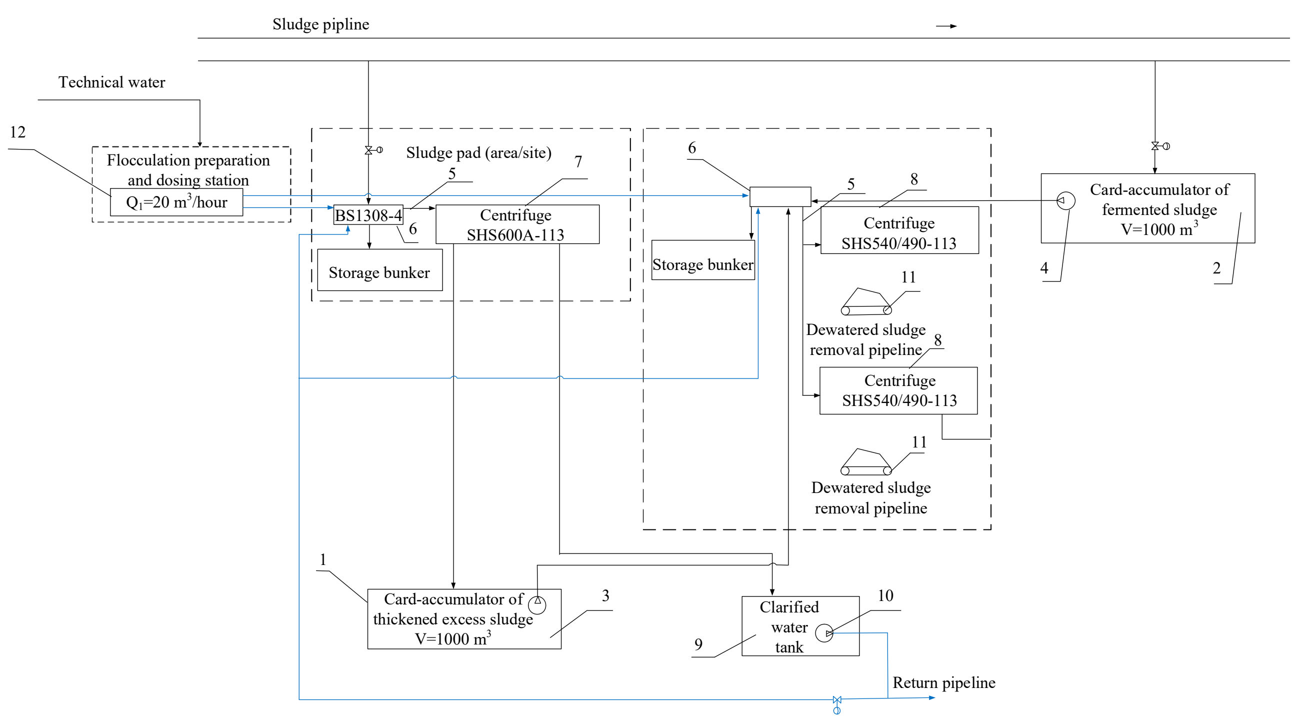

Fig. 4. Technological scheme of the activated sludge thickening and dewatering module at municipal wastewater treatment plants: 1 – card-accumulator of thickened excess sludge; 2 – card-accumulator of fermented sludge; 3 – pump of thickened excess sludge; 4 – pump of fermented sludge; 5 – sludge moisture sensor; 6 – drum screen; 7 – centrifuge SHS600A-113; 8 – centrifuge SHS540/490-113; 9 – clarified water tank; 10 – clarified water pump; 11 – belt conveyor; 12 – flocculation preparation and dosing station

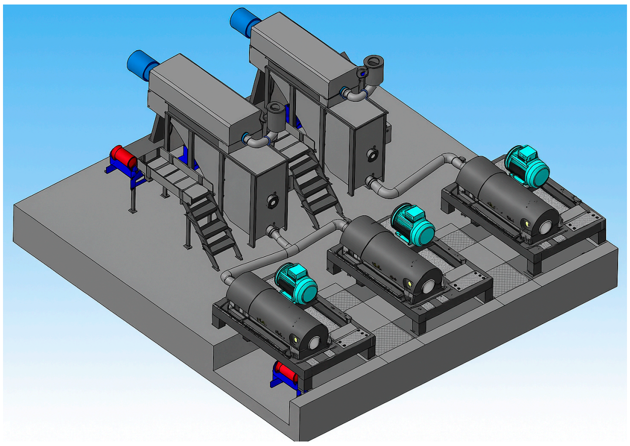

Fig. 5. Model of the thickening and dewatering module for excess activated sludge from municipal wastewater treatment plants

6. Discussion of results related to coal dust capture and dehydration of sludge from gas purification at thermal power plants

As a result of our study on the separation of excess and stabilized sludges selected at BAS, it was found that effective separation and thickening of sludge is possible under conditions of a separation factor of up to 600–700 according to Fig. 2, 3. Stabilized activated sludge is partially mineralized during the fermentation process, flocculates, and thickens more effectively.

Most attention was paid to determining the optimal sludge mixing modes, centrifugation parameters, and assessing the stability of the dehydration process with a variable composition of sludge. Our results could become the basis for the development of energy-efficient and technologically adaptive solutions for implementation at treatment facilities, which would contribute to reducing the volume of sludge, increasing the degree of its dehydration, reducing reagent consumption, and minimizing environmental impact.

The process of separation of excess and stabilized activated sludge in a laboratory centrifuge depends on the separation factor (*Fr*), the concentration of the solid phase, and the use of flocculant. Analysis of Table 1 reveals that for EAS (5 g/l) effective separation is achieved at $Fr = 600–700$, when the volume of the thickened product decreases to 14% (with and without flocculant), and the humidity decreases to 96.8% (Fig. 2). Stabilized EAS (14 g/l, Table 2) is better densified due to mineralization, reaching 24.5% of the thickened product with flocculant at $Fr = 600$ (Fig. 3). The use of flocculant intensifies the separation at $Fr = 200–600$, but at $Fr = 1000$ the differences disappear. Low efficiency at $Fr < 200$ is due to weak particle aggregation. These results are consistent with studies on the dehydration of excess activated sludge from biological treatment plants [14]. A mineral component is required for mechanical dehydration, which confirms the feasibility of mixing sludges in a pilot module (Fig. 4, 5).

The limitations of our study are related to the variability of the composition of sludge at different treatment plants, which requires adaptation of parameters. The disadvantage is the lack of industrial testing of the module. The prospect is to improve centrifuges to improve the efficiency of dehydration at $Fr > 1500$.

The separation of sludge and suspensions in industrial centrifugal units is a multifactorial process, which is influenced by the operating mode of the centrifuges, the characteristics of the liquid mixtures being separated, and other factors. Analyzing the results of Tables 3, 4, it can be concluded that the low efficiency of the centrifuge (Table 4, items 1–4) is a consequence of the low separation factor (199.11) and low sludge concentration in the centrifuge feed. This leads to the creation of conditions that are not favorable for the formation of a thickened product in the absence of effective particle aggregation during flocculation. The most favorable conditions for the separation of this product are formed at a separation factor of 448–525 (items 5–10). However, increasing the centrifuge feed productivity to 19.2 m^3/hour in the experiment (Table 4, item 5) reduces the residence time of the flow in and leads to unsatisfactory results. An increase in the concentration of activated sludge to 11.9 g/l in the experiment (Table 4, item 9) explains the significant increase in the sludge concentration to 6.8 g/l and its introduction into the clarified fugate. The absence of flocculants in the experiments (Table 4, items 11, 12) also worsens the thickening efficiency and leads to the solid phase entering the fugate. These justifications are fully consistent with similar patterns identified in previous studies [10, 14].

Thus, the application of mechanical dehydration requires the selection of optimal centrifuge operating parameters, which is reduced to conducting research with real liquids.

Sludges containing a mineral component for the formation of a sediment structure that is consistent with research [14] may be suitable for mechanical dehydration in a centrifuge or in a filtration technique. In this regard, in the designed pilot module (Fig. 3, 4), it is planned to use fermented sludge or a mixture of fermented sludge and excess activated sludge for dehydration. Depending on the proportions of mixing the sludges, the moisture content of the dehydrated sludge may vary, which requires additional research. Compaction of excess activated sludge (without mineral base and addition of fermented sludge) is possible in more efficient high-speed centrifuges ($Fr > 1500$).

The limitations of our study are that the composition and properties of sludge from different treatment plants in different countries and cities have their specific characteristics and may differ from each other. Therefore, the patterns established, as well as recommendations, need to be refined depending on the specific activated sludge that must be dewatered.

The disadvantages of conducting the studies described are the lack of experimental verification of the operation of the designed module directly at the production facilities at urban treatment plants.

The prospect of further research is to improve the design features of centrifugal units, providing for an increase in the efficiency of activated sludge dewatering.

7. Conclusions

1. As a result of our studies on the efficiency separating fermented sludge and excess activated sludge into a liquid phase and sediment in a laboratory centrifuge, it was found

that separation into sediment and a clarified product can occur at a separation factor of up to 200–600 using a flocculant. Fermented activated sludge is better dewatered at a low separation factor.

2. As a result of industrial tests of a centrifugal installation at a separation factor of 200–600, stable operation of an industrial sedimentation centrifuge was noted under various technological regimes. The most effective separation was observed at a separation factor of 450 and a centrifuge feed of 9.4 m^3/hour using a flocculant. Increasing the centrifuge productivity, increasing the concentration of activated sludge, or reducing the separation factor lead to a decrease in the solid phase content in the thickened product and an increase in it in the clarified liquid.

3. A two-stage dehydration scheme has been proposed, which includes the stages of preliminary thickening and subsequent mechanical dehydration of sludge mixtures in Ecomash-type centrifuges. During the operation of the pilot module, optimization of operating modes, reagent dosages, and mixing proportions is carried out, which makes it possible to obtain sludge with a humidity of 65–85% and significantly reduce the volume of sludge masses, improving their suitability for further disposal or energy use.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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