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TECHNOLOGICAL EQUIPMENT FOR DEWATERING SLUDGE WITH A HIGH MINERAL CONTENT

Sludge dewatering is a critical stage in the wastewater treatment process, allowing for a reduction in sludge volume, optimization of transportation and disposal costs, and stabilization of the material for further processing or disposal. Current trends in the use of equipment for wastewater sludge dewatering processes are analyzed. The design features and limitations of certain types of equipment are indicated. A particular challenge is the treatment of sludge with a high content of mineral impurities, which cause intensive wear of equipment, blockage of flow, and complications in the operation of traditional dewatering methods. The use of filter presses and centrifuges in such conditions is ineffective, which necessitates the search for more reliable and energy-efficient technologies. Roller presses demonstrate potential advantages due to reduced abrasive impact, low energy consumption, and compact design. The purpose of this study is to evaluate the effectiveness of preliminary sludge treatment using a sand separator before feeding it to a roller press. The research methodology is presented. Sludge formed as a result of dry anaerobic fermentation of household waste at a waste sorting plant was selected as the object for dewatering. The technological scheme of the wastewater dewatering process is considered in detail. The physicochemical characteristics of the sludge before and after separation were analyzed, and the load on the press shafts was measured. The design of the filtration equipment is presented and its operating principle is described in detail. A comparative analysis of the sludge before and after treatment in a sand separator showed a significant improvement in both the physicochemical characteristics of the flow and the stability of the equipment operation. The results obtained allow us to assess the feasibility of integrating a sand separator into the dewatering scheme and its impact on the stability of the equipment operation.

Keywords: *sludge dewatering, wastewater, minerals, energy efficiency, sand separator, roller press, system efficiency, mechanical wear*

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ТЕХНОЛОГІЧНЕ ОБЛАДНАННЯ ДЛЯ ЗНЕВОДНЕННЯ ОСАДУ З ВИСОКИМ ВМІСТОМ МІНЕРАЛЬНИХ РЕЧОВИН

Зневоднення осаду є критичним етапом у процесі очищення стічних вод, що дозволяє зменшити об'єм осадових мас, оптимізувати витрати на транспортування та утилізацію, а також забезпечити стабілізацію матеріалу для подальшої переробки або видалення. Проаналізовано сучасні тенденції у використанні обладнання для проведення процесів зневоднення осадів стічних вод. Вказано особливості конструкцій та обмеження певних типів обладнання Особливу складність становить обробка осаду з підвищеним вмістом мінеральних домішок, які викликають інтенсивне зношення обладнання, блокування потоку та ускладнення експлуатації традиційних методів зневоднення. Застосування фільтр-пресів і центрифуг у таких умовах виявляється малоефективним, що обумовлює необхідність пошуку більш надійних та енергоощадних технологій. Роликові преси демонструють потенційні переваги завдяки зменшенню абразивного впливу, низькому енергоспоживанню та компактності конструкції. Метою цього дослідження є оцінка ефективності попереднього очищення осаду за допомогою піскового сепаратора перед його подачею на роликовий прес. Наведена методологія проведення дослідження. У якості об'єкту було обрано для зневоднення осади, які формуються внаслідок сухої анаеробної ферментації побутових відходів на сміттєсортувальному підприємстві. Докладно розглянута технологічна схема процесу зневоднення стічних вод. Проведено аналіз фізико-хімічних характеристик осаду до та після сепарації, а також було виміряно навантаження на вали пресу. Наведено конструкцію фільтрувального обладнання та докладно описано принцип його роботи. Порівняльний аналіз осаду до та після обробки в пісковому сепараторі засвідчив суттєве покращення як фізико-хімічних характеристик потоку, так і стабільності експлуатації обладнання. Отримані результати дозволяють оцінити доцільність інтеграції піскового сепаратора у схему зневоднення та його вплив на стабільність роботи обладнання.

Ключові слова: *зневоднення осаду, стічні води, мінеральні речовини, енергоефективність, пісковий сепаратор, роликовий прес, ефективність системи, механічний знос.*

Introduction. Wastewater treatment is a multi-stage process that includes both biological and mechanical methods of treating contaminated flows. One of the most important stages is sludge dewatering, which significantly reduces the volume and weight of the residues formed, thereby reducing the operating costs of transportation and disposal, as well as improving the hygienic and environmental characteristics of the final product. However, in cases where the sludge contains a large amount of abrasive mineral impurities (e.g., sand, glass, soil or sludge microparticles), traditional equipment faces serious operational problems. Accelerated wear of mechanisms, an increase in the number of emergency stops, and a decrease in process efficiency all require the implementation of additional technological solutions. One promising direction is the use of sand separators as a preliminary stage of sludge treatment before dewatering. This reduces the content of solid mineral inclusions in the flow, thereby reducing the load on the main equipment. Of particular relevance is research into the effectiveness of such a system in combination with roller presses, which are considered an energy-efficient alternative to traditional methods. Traditionally, technologies such as belt filter presses, chamber filter presses, and centrifuges are used for sludge dewatering. However, in cases where the sludge contains a significant amount of abrasive particles, these technologies may be less effective due to high wear on the working elements. This creates a need to find more reliable and energy-efficient solutions for processing such sludge.

This article discusses the experimental implementation of a sand separator in the dewatering process chain, evaluates the parameters of the sludge before and after pre-treatment, and analyzes the load on the press equipment. The aim of the study is to determine the effect of pre-separation on the stability of the roller press and the overall efficiency of dewatering.

Current status of the problem. Wastewater sludge dewatering is an important step in the technological process of treatment, which plays a key role in minimizing waste and ensuring the environmental sustainability of enterprises. Efficient dewatering reduces the volume of sludge for further disposal and reduces the cost of its transportation and storage. There are several main sludge dewatering technologies, with the most common being filter presses, centrifuges and roller presses. Each of these technologies has its advantages and disadvantages depending on the sludge composition and operating conditions.

Filter presses are widely used for sludges with a high organic content, as they provide a high degree of dewatering, but this equipment requires significant energy consumption and frequent maintenance. It is particularly problematic to use them when treating sludge containing abrasive particles such as sand or glass, which reduce efficiency and increase wear of the filter elements [1]. Centrifuges are effective when dealing with wastewater containing chemically active or inorganic substances, but due to their high rotor speeds, they are subject to significant wear and tear when dealing with inorganic-rich sludge. This leads to increased maintenance costs and can reduce the durability of the equipment [2].

Recently, disc dehydrators have gained popularity due to their energy efficiency and compactness. They reduce energy consumption compared to other methods and can be used for various types of sludge, including those containing high levels of inorganic substances [3]. Roller presses are a promising alternative for the dewatering of sludges containing large amounts of abrasive particles. These presses are highly resistant to wear and tear, as the design minimizes contact between the abrasive particles and the working elements of the equipment. This allows for greater durability and reduced energy consumption compared to centrifuges, making them cost-effective for enterprises [1].

In review about dewatering of sewage sludge [4] is discussed the use of belt filter presses and centrifuges for sludge dewatering, focusing on the mechanics of water removal and new developments in high-solids centrifuges. The reference [5] examines the dewatering of sludge using diaphragm plate-and-frame filtration, focusing on improvements in throughput and solids concentration. A comparative study of centrifuges and belt filter presses in terms of dewatering efficiency, cost, and polymer requirements presented in reference [6] Compares centrifuges and belt filter presses, analyzing dewatering performance and cost.

In reference [7] reviews filtration technologies like membrane presses and decanter centrifuges for sludge dewatering, with a focus on compressibility and particle size. Investigates the efficiency of electro-dewatering technology for reducing sludge volume and its potential for decontamination presented in work [8]. Critical review on dewatering of sewage sludge [9] discusses various sludge dewatering technologies and their environmental implications, with an emphasis on chemical conditioning methods. Shevchenko, A., Shevchenko, T. [10] examines the advantages of application of containerized sludge dewatering plants, as well as the rationale for the use of MDQ multi-disc dehydrators. The main focuses are placed on considering the technical features of the equipment in terms of capital and operating costs, as well as equipment maintenance. Authors [11] focus on deep-dewatering technologies, such as chemical preconditioning and electrical-mechanical dewatering, to improve sludge dewatering efficiency.

In reference [12] reviews various pretreatment technologies like thickening, conditioning, and dewatering, including centrifuges and belt filter presses. Multivariate data analysis of full-scale sludge dewatering presented in reference [13].

High-dry dewatering of sludge based on different pretreatment conditions reviewed in reference [14]. Electro-dewatering is an energy-efficient method for dewatering wastewater sludge, but its effectiveness may be limited by the sludge's electrical conductivity and microbial content [15]. In reference [16] describes the use of a hydraulic press system, originally from the food industry, for more effective dewatering of sewage sludge. Kim, S. [17] focused on improved waste-activated sludge dewatering. Citeau, M. and Olivier, J. [18] investigates the use of electro-osmotic dewatering to increase dry solids content in sludge dewatering.

It should also be noted that the quality of the filtrate after dewatering can vary depending on the technology used. Centrifuges can produce leachate with a high content of suspended solids, which requires additional treatment. Roller presses, on the other hand, provide better filtrate quality, which reduces the load on subsequent treatment stages [2]. Thus, the use of roller presses is a promising solution for companies dealing with sludge with a high content of inorganic substances. This technology ensures efficient dewatering with reduced energy consumption, long equipment life and high quality filtrate [3]. Roller press technology has made significant strides in terms of design, capacity, and durability. Advances in modeling and simulation have enabled better optimization of these machines, while modular design principles have improved their flexibility and efficiency. These developments have broadened the application of roller presses across various industries, ensuring better performance and longer service life.

Research methodology. The object of the study was a system for dewatering sludge formed as a result of dry anaerobic fermentation of household waste at a waste sorting plant. At the inlet, the sludge has a dry matter content of 8–16% (Fig. 1) and is characterized by an increased content of mineral impurities (up to 64%), significant viscosity, and abrasiveness, which complicates the use of traditional mechanical dewatering methods. An excessive amount of solid inclusions, such as sand, slag, glass, and soil microparticles, causes rapid wear of working components, frequent equipment blockages, and reduced process stability.

In order to assess the feasibility of introducing a sand separator as a preliminary cleaning stage prior to dewatering, the study was conducted on a pilot industrial line consisting of a sand separator and a roller press manufactured by ESMIL (Fig. 2). The technological scheme included preliminary cleaning in a sand separator, which made it possible to effectively reduce the mineral content to a level that ensured safe delivery of sludge to the press without the risk of blockage or damage (Fig. 3).

Figure 1 – Photo of dehydrated sludge after roller press

Figure 2 – Photo of the installation at the facility

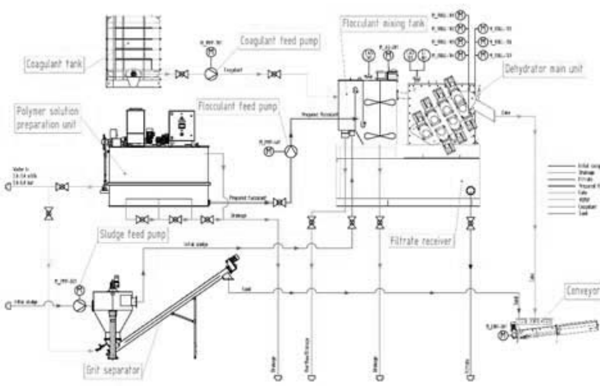
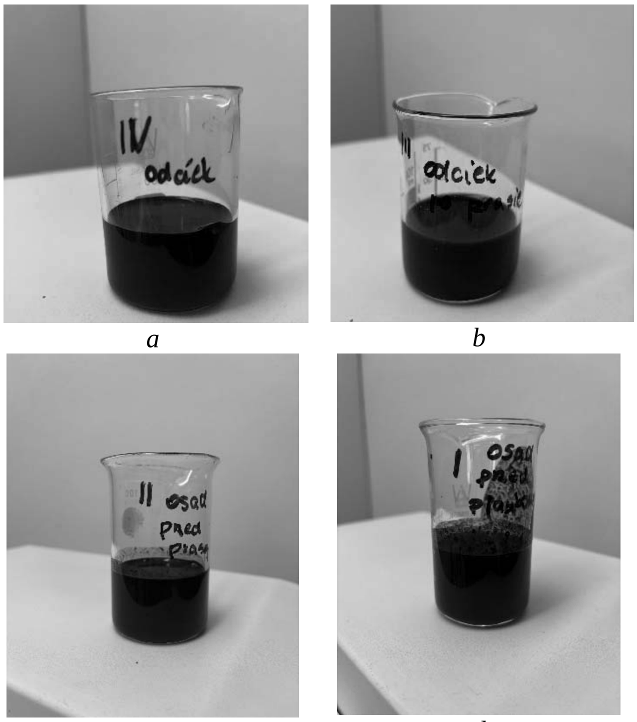


Figure 3 – Technological diagram of the dehydration process

After passing through the sand separator, the sediment was fed into the flocculation tank of the roller press, where the reagents were dosed. PAX 18 polyaluminium chloride (18% Al_2O_3) was used for coagulation, which was fed from a tank using a regulated pump. The flocculant Ekoline PFC 7500S in the form of a solution with a concentration of 0,1–0,12% was prepared at a special dosing station and also fed into the flocculator by a pump with flow control. The selection of reagents was carried out by a subcontracted laboratory through a series of laboratory tests (Fig. 4).

To accurately assess the impact of preliminary separation, four types of sediment samples were collected and analyzed: filtrate after pressing without using a sand separator, filtrate after pressing with a sand separator, sediment before the sand separator, and sediment after it – immediateely before entering the roller press. Visual analysis confirmed the change in the structural characteristics of the sediment after separation, and laboratory tests revealed differences in the content of dry matter and mineral inclusions.



a *b*

c *d*

Figure 4 – Appearance of biomass waste used in the research:
a – filtrate after pressing without using a sand separator,
b – filtrate after pressing using a sand separator, *c* – sediment on the feed line to the roller press before the sand separator,
d – sediment on the feed line to the roller press after the sand separator, immediately before the roller press

The key analytical method in the study was the determination of total dry matter (TS) content. Samples weighing 5 g were calcined in a muffle furnace at 550 °C for 5 hours. After cooling in a desiccator, the ash residue was determined, and the mass fraction of ash substances was calculated using the classical formula:

$$A = \frac{m_3 - m_1}{m_2 - m_1} \cdot 100\%, \qquad (1)$$

where m_1 – mass of the empty crucible, g; m_2 – mass of the crucible with the wet sample, g; m_3 – mass of the crucible after calcinations, g.

a *b*

Figure 5 – Calcining process equipment and outcome:
a - LAC muffle oven, *b* – samples of biomass raw materials under study in porcelain crucibles after calcination at 550˚C

In addition to laboratory analysis, the study included measurements of the roller press's operating parameters: shaft loads, number of emergency stops, changes in filtrate quality (turbidity, suspended solids content), and an assessment of total energy consumption. The shaft load data was taken from the readings of frequency converters installed on the drive motor-reducers of the roller press and measured as a percentage of the rated torque.

Figure 6 – Frequency converter indicators

Research results. The schematic diagram of the filter unit and the principle of operation of the roller press is shown in Fig. 7 and Fig. 8. The roller press consists of two main parts, which are located next to each other and connected by a feed channel. One part of the press is mounted on a frame, the other part is mounted on a tank for collecting filtrate. The tank mounted on the frame is divided into two sections: a dosing tank and a flocculation tank. The partition between the sections has a V-shaped overflow. The flocculation tank contains a motor-driven agitator for mixing the sludge with the reagent to form flocs, after which the sludge is fed to the dewatering unit located above the filtrate collection tank.

The trough for receiving and discharging the filtrate is located under the dewatering unit.

The sludge is fed to the inlet of the dosing chamber by a pump. After chemical treatment, the sludge is fed to the dewatering unit.

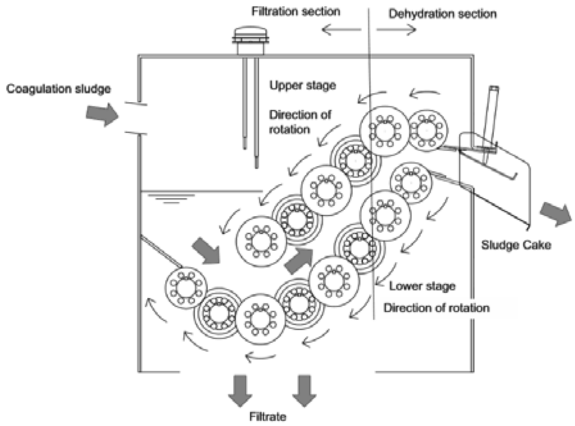


Figure 7 – Schematic diagram of the filter unit

Each filter roller consists of thick resin discs, small thin stainless steel discs, and large thin stainless steel discs. Gaps are formed between adjacent discs, through which only water flows. The larger discs of the filter rolls engage with the smaller discs of the adjacent filter rolls, which helps to keep the gaps clean.

The filter rollers are arranged so that the distance between the upper and lower rows gradually decreases from the sludge inlet to the sediment outlet, resulting in sludge compression. In addition, the filter rollers in the dewatering zone rotate more slowly than in the filtration zone and, together with an adjustable damper installed at the sludge outlet, perform dewatering. The dewatered sludge is discharged through a sludge chute equipped with a partition that creates additional pressure on the sludge. This feature allows you to adjust the solids content in the sediment.

The principle of operation of the sand separator is shown in Fig. 9.

The inlet and outlet pipes are installed in the upper part of the tank. Devices for washing sand with inlet and outlet branches for washing water are installed in the lower part of the conical tank. The mixing device is installed inside the tank and is driven by a gear motor. Another gear motor drives the sand conveyor screw. The sand conveyor, consisting of several housings with rotating screws inside, is installed on the tank at an angle of 35°. The rounded body of the sand conveyor is protected by wear-resistant polymer inserts. The sections of the housing are connected by flanged couplings.

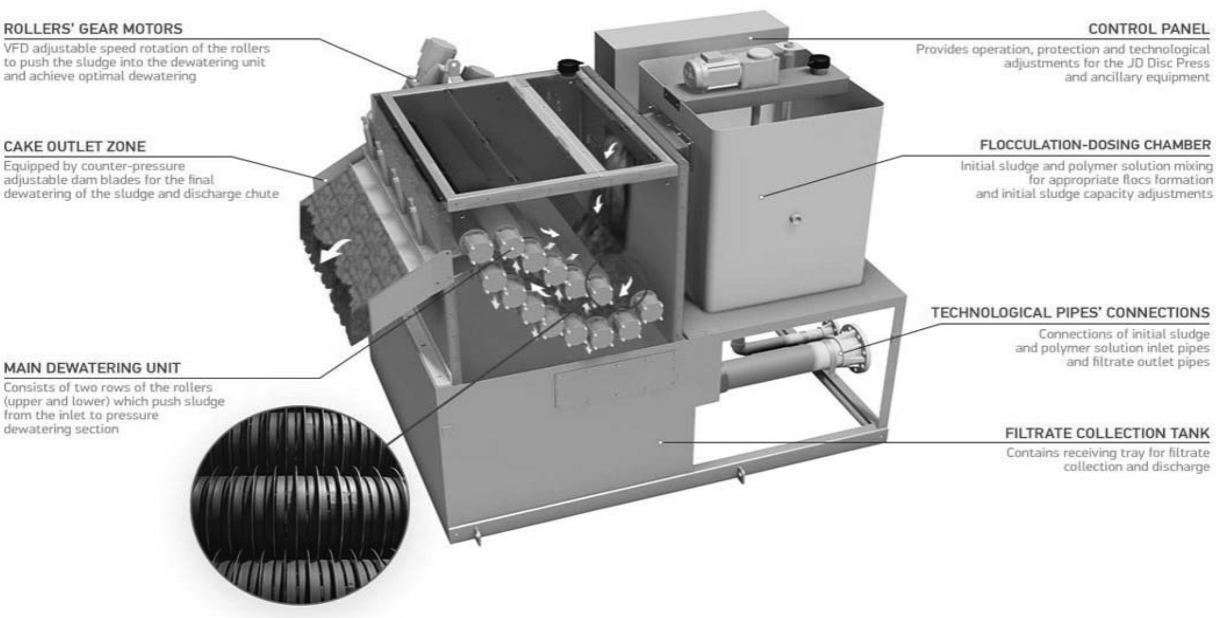


Figure 8 – View of the roller press

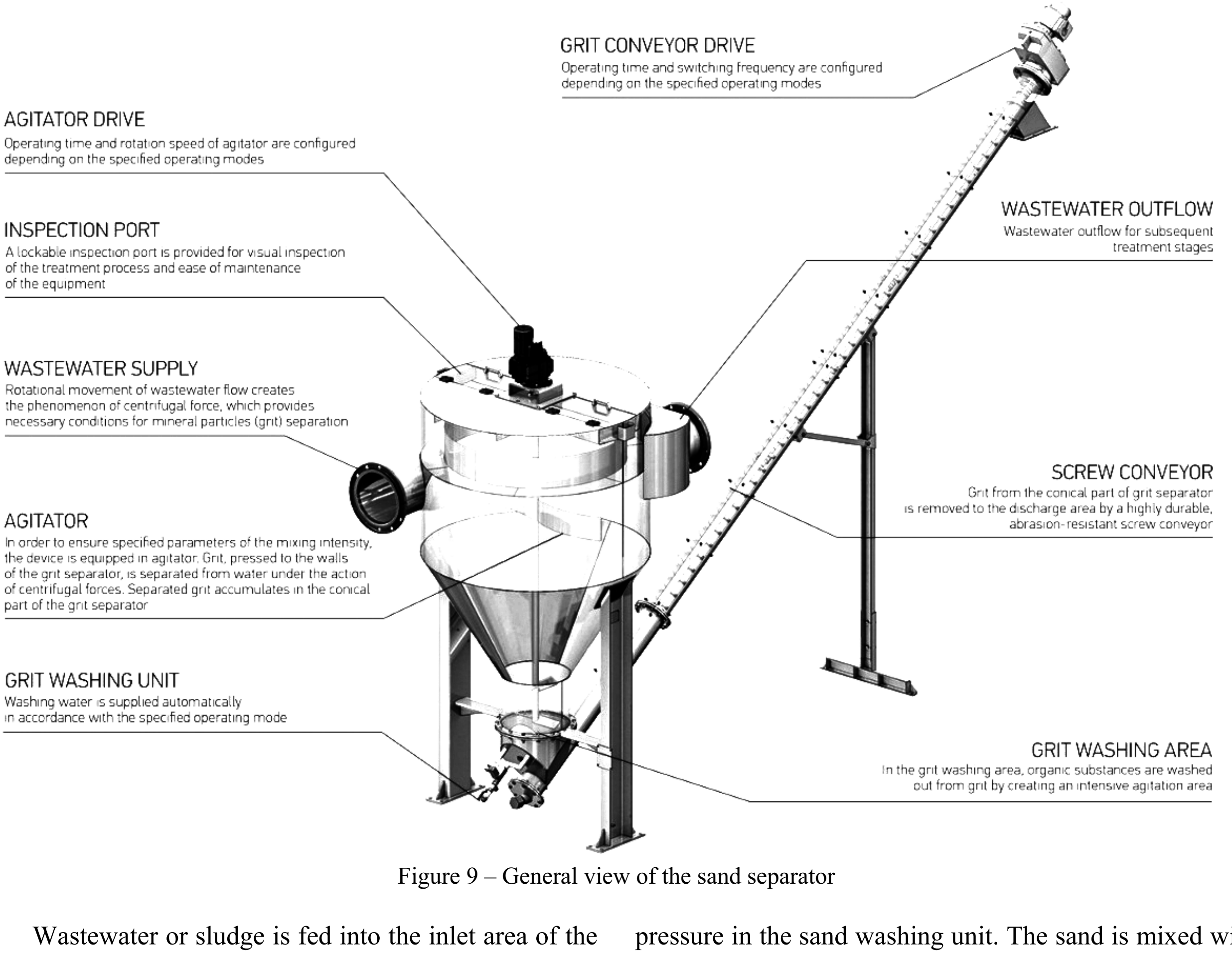


Figure 9 – General view of the sand separator

Wastewater or sludge is fed into the inlet area of the conical tank and swirled along the walls of the tank by the rotation of the mixing device. The sand slides down the walls of the conical tank and enters the sand washing unit. The treated wastewater or sludge is sent to the outlet pipe for further treatment. The sand is washed under water pressure in the sand washing unit. The sand is mixed with a mixer to improve the washing process. The wash water is drained to the next stages of treatment, and the sand is collected at the bottom of the tank. From there, it is transported to the unloading area by a screw conveyor. The sand is unloaded into a container or onto a conveyor.

A comparative analysis of the sediment before and after treatment in a sand separator showed a significant improvement in both the physical and chemical characteristics of the flow and the stability of equipment operation. The main results are presented in two areas: changes in dry matter content and the load on the roller press shafts.

The total dry matter content in the samples is shown in Figure 10 in the form of a diagram.

Based on the results of the research, it was found that the highest total dry matter content, which is 5,124%, is characteristic of sludge before the sand separator. A significantly lower total dry matter content of 3,809% is characteristic of the sediment before the press, an even lower content (3,776%) is characteristic of the filtrate after the press without the use of a sand separator, and the lowest was found in the filtrate after the press without the use of a sand separator, and the filtrate after the press with the use of a sand separator was 1,461%.

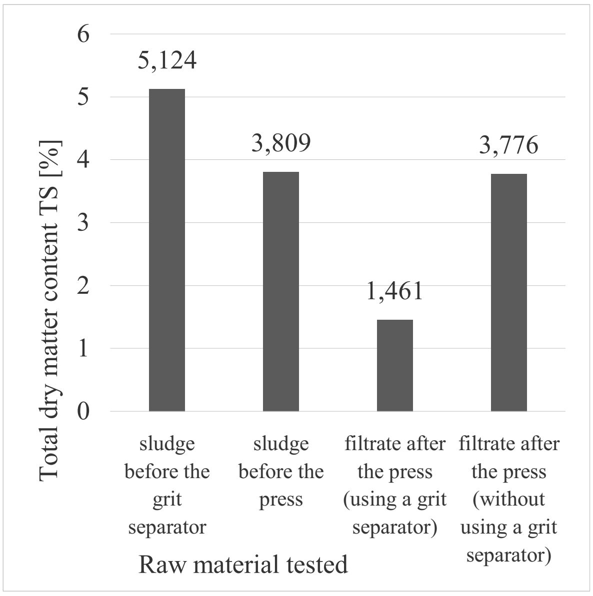


Figure 10 – Total dry matter content in samples

The loads were taken from the readings of frequency converters installed separately for each zone of the dewatering unit. The division into zones is shown in Fig. 11. The comparison of loads on the roller press shafts, with and without the use of a sand separator, is presented in Table 1 and measured as a percentage of the nominal torque.

Table 1 – Load on shafts

Division	Load on shafts without using a grit separator, %	Load on shafts with using a grit separator, %
Thickening zone	50…60	40…50
Filtering zone	85…90	65…70
Dewatering zone	100…110	90…95

This means that the load on the shafts and main moving parts of the roller press is reduced by 20% when the sand separator is installed, thereby increasing the service life of these parts.

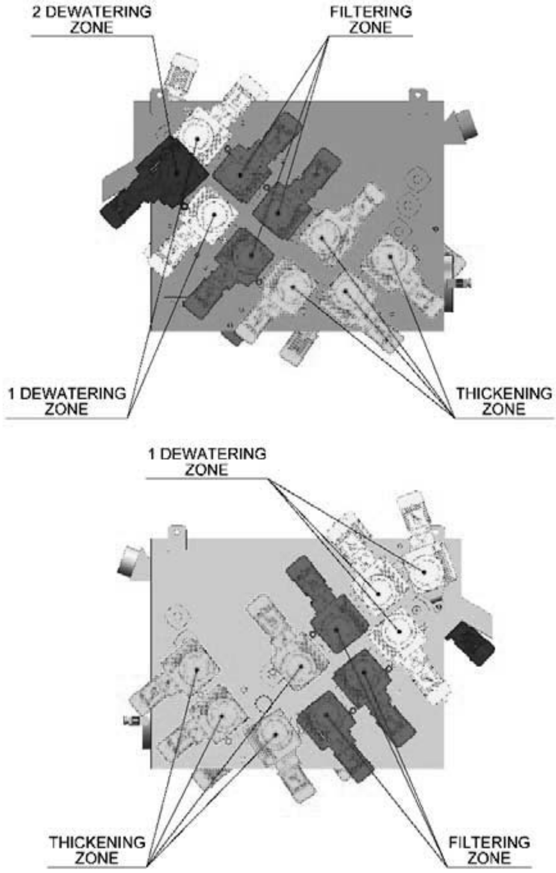


Figure 11 – Zones of the dewatering unit

Conclusions. The study proves that the installation of a sand separator upstream of the roller press in the process of dewatering sludge with a high content of mineral impurities is a technically feasible and effective solution. Preliminary sludge cleaning significantly reduces the abrasive load on the equipment, which manifests itself in a reduction in the load on the roller press shafts in all areas of operation – from compaction to dewatering. This, in turn, increases operational reliability, reduces the frequency of equipment downtime due to accidents, and extends the service life of moving parts.

There is also an improvement in the quality of the filtrate: after passing through the sand separator, the sludge has a lower concentration of mineral inclusions, which reduces turbidity and increases the efficiency of subsequent processing stages. In addition, reducing the solid load helps to stabilize the process, reduce energy consumption, and optimize maintenance costs. Overall, the combination of a sand separator with a roller press provides a more reliable, controllable, and energy-efficient dewatering process, especially when treating complex, abrasive sediments. This solution is promising for implementation at facilities where conventional dewatering methods are not effective enough due to the high content of mineral impurities.

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