Application of ultrasonic disintegration of post-coagulation sludge

Zastosowanie dezintegracji ultradźwiękowej dla osadu pokoagulacyjnego

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Disintegration of sludge is a process consisting of the destruction of sludge flake structure, followed by rupture of the cell membrane and lysis of the microbial cells. Disintegration processes constitute a rapidly growing technology that is gaining more and more interest. The disintegration process results, inter alia, in the breaking of strong chemical bonds, therefore, it can be effective in the case of post-coagulation sludge. For this type of sludge, the expected effect is to improve its filtration properties. The integrated action between microorganisms and the cells alone, results in the release of the organic matter and biological water from inside of the cell. The process of sludge disintegration can be carried out using the following techniques: mechanical, thermal, chemical, or biological. The choice of a disintegration method is not simple because its effects are dependent on many parameters. One of those methods is ultrasonic application. Ultrasonic can negatively affect living organisms. It directly affects walls and membranes' cells, leading to their deformation, perforation, or cell death. During the studies the following sludge parameters were determined: capillary suction time (CST), total solids (TS), volatile solids (VS), hydration and COD of supernatant liquid. After the disintegration process, it was observed that the value of TS increased from 0.04 % to 0.06% in the case of the longest exposure time of the sludge to the ultrasonic waves. It was also observed that the longer the process time and higher amplitude, the higher the COD value of the liquid. However, the capillary suction time decreased from 53 s for the non-disintegrated sludge to 25 s for the sludge subjected to ultrasonication – 50% amplitude and 10 minutes. This demonstrates the improvement of the filtration properties of sludge after disintegration.
Keywords: ultrasonic disintegration, post-coagulation sludge, sludge from water treatment plant

Dezintegracja osadu jest procesem polegającym na zniszczeniu struktury kłaczków osadu, a następnie rozerwaniu błony komórkowej i lizie komórek drobnoustrojów. Procesy dezintegracji to obecnie dynamicznie rozwijające się technologie, które cieszą się coraz większym zainteresowaniem. Zastosowanie procesu dezintegracji skutkuje między innymi zerwaniem silnych wiązań chemicznych, dlatego może być skuteczny w przypadku osadów pokoagulacyjnych. Dla tego typu osadów oczekiwanym efektem jest poprawa ich właściwości filtracyjnych. Zintegrowane działanie mikroorganizmów i samych komórek powoduje uwolnienie materii organicznej i wody biologicznej z wnętrza komórki. Procesy dezintegracji osadów można przeprowadzić przy pomocy technik: mechanicznej, termicznej, chemicznej lub biologicznej. Wybór danej metody nie jest prosty, gdyż efekty zależą od wielu parametrów. Jedną z metod dezintegracji są ultradźwięki. Ultradźwięki mogą negatywnie wpływać na organizmy żywe. Oddziałując bezpośrednio na komórki ścian i błon, prowadzą do ich deformacji, perforacji lub śmierci komórek. W badanym osadzie pokoagulacyjnym przed i po procesie dezintegracji wykonano oznaczenia: czas ssania kapilarnego (CSK), zawartość suchej masy (SM), zawartość suchej masy organicznej (SMorg), uwodnienie, oraz ChZT cieczy nadosadowej. Po procesie dezintegracji zaobserwowano, że wartość SM wzrosła od 0,04 % do 0,06% w przypadku najdłuższego czasu ekspozycji osadu na działanie ultradźwięków. Zaobserwowano również, że im dłuższy czas naświetlania, tym wyższa wartość ChZT cieczy. Natomiast czas ssania kapilarnego uległ skróceniu z 53 s dla osadu niedezintegrowanego do 25 s dla osadu poddanego nadźwiękawianiu – amplituda 50%, czas10 min. Świadczy to o poprawie właściwości filtracyjnych osadu po procesie dezintegracji.
Słowa kluczowe: dezintegracja ultradźwiękowa, osady pokoagulacyjne, osady z produkcji wody

Introduction

The processes used in the technological treatment of water are accompanied by the formation of large amounts of sludge and technological wastewater. The amount of sludge formed is from 2 to 5% of the volume of treated water. For this reason, sludge is problematic for water treatment plant operators, since their significant quantities require disposal. Sludge form water treatment plants in accordance with the Regulation of the Minister of Climate of January 2, 2020 is considered waste and classified under code 19 09 02. According to the law, it must be subjected

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to recovery and disposal processes [1-5]. Technological solution are still being sough to enable the reduction of amount of sludge from water treatment plants, as well as their appropriate use and management.

The most commonly used surface water treatment processes are coagulation and filtration. Therefore, the main waste products from water treatment plants are post-coagulation sludge. The coagulation process is used to remove colloidal and inorganic impurities and finely dispersed suspended solids from water, which cause color and turbidity. In addition, sludge from surface water treatment may also contain microorganisms such as bacteria (Escherichia coli, Salmonella, Pseudomonas aerubinosa, Legionella), protozoa (Cryptosporidium), viruses, cysts of the parasites Cryptosporidium parvum and Giardia lamblia, or cyanobacteria and the cyanotoxins they produce. [2]. This sludge may also periodically contain phytoplankton when algal blooms appear in the reservoir. Post-coagulation sludge has a flocculation structure. The shape of the flocs is very irregular and the pores are filled with water. Their density is not much different from the density of water. The irregular shape of the floc makes their movement very complex. The porosity of the flocs is related to the presence of a large number of channels. The channels are formed by the aggregation of colloidal particles. Freshly formed flocs showed the greatest ability to combine (the adsorption surface is then the largest). Over time, the flocs become compacted and aged, and the adsorption surface area decreases [6].

According to literature data, post-coagulation sludge can be used for the production of cement, bricks, tiles and ceramic pipes. Adding ash from burn sludge generated from water treatment plants to cement increases durability and resistance to sulphate corrosion. On the other hand, the use of aluminum or iron-containing sludge for the production of bricks improves the intensity of red color [1, 7]. In addition, it is possible to recover coagulants as well as CaO and CO_2 from sludge formed during lime water softening from post-coagulation sludge. At the same time, the higher cost of aluminum coagulant than the cost of iron coagulant means that the recovery of the former is more profitable. This method involves dissolving post-coagulation sludge with lye or acids. Studies have shown that the use of NaOH is not effective because the resulting $NaAlO_2$ has poor coagulation properties.

For this reason, the acid method, which uses salt or sulfur cash registers for digestion, is more effective. The products of this process are $AlCl_3$ and $Al_2(SO_4)_3$. In addition to dewatering and drying of sludge, they are often roasted, which ensures the thermal mineralization of organic substances. At temperatures above 1000 °C, Al_2O_3 is formed, which is easily soluble in acid. The products formed during the acid sludge digestion process are a solution of recovered coagulant and undissolved sludge, the content of which reaches 17-30% of the volume of raw sludge. The recovered coagulant is usually added to the purified water along with the fresh coagulant. However, sludge must be dewatered and managed in an appropriate manner [1, 8, 9].

In the case of municipal sewage sludge, its treatment aims to improve its filtration properties, and thus its susceptibility to dewatering. To this end, conditioning and disintegration processes are used. In addition, sludge disintegration can be considered as one of the conditioning processes. Disintegration processes enable the destruction of cell membranes of microorganisms and the release of organic substances and biologically bound water from them. The disintegration processes use ultrasonic waves [10-13], homogenization [14], microwave radiation [15-19], thermal processing [20], and ozonation [21]. Choosing a disintegration method is not easy because the effects obtained during the process depend on many factors. The most important factor is the characteristics of the sludge itself.

The application of ultrasonic waves is one of the disintegration methods used in the case of sewage sludge due to the possibilities of using the technological process. During the ultrasonic disintegration process, sounds with a quite narrow range of frequencies are produced: between 10 kHz to 50 kHz. Due to its very complex interaction in solid-liquid systems, the ultrasonic field can cause profound physicochemical changes in sonicated sludge. During the process, cell walls are destroyed, which causes the release of cytoplasm and cellular enzymes. The obtained effects of ultrasonic disintegration depend on many parameters, from which three basic groups can be distinguished: characterizing the tool (the shape and size of the emitter), characterizing the area (the position of the emitter in relation to the walls and bottom of the sonication chamber and the sludge mirror), and characterizing the disintegration environment (related to the properties of the sludge). The main advantages of ultrasonic disintegration are the lack of the need to use chemicals and the possibility of encapsulating the facilities. Ultrasonic reactors consist of a generator, electroacoustic transducers, an emitter, and a disintegration chamber. Using a transducer, the generator's electrical vibrations are converted into mechanical vibrations with an acoustic frequency. Then, using an emitter, they are transmitted in the form of ultrasonic waves to the sonicated medium [22,23].

The article presents the results of studies on the use of ultrasonic processes for the disintegration of post-coagulation sludge from a water treatment plant. As previously mentioned, information regarding research on the disintegration of municipal sewage sludge can be found in the literature. In turn, post-coagulation sludge is characterized by different physicochemical properties than municipal sewage sludge.

Research methodology

Disintegration tests were carried out for post-coagulation sludge from a water treatment plant (Fig. 1). Water treatment technology is based on the processes of volumetric coagulation/flocculation and sedimentation. The coagulation/flocculation process uses a pre-hydrolyzed aluminum coagulant and an additional mineral load. The mineral load binds to the flocs and improves their subsequent sedimentation. The flocs produced in the coagulation/flocculation process are then separated from the water by sedimentation in a settling tank equipped with lamellas. The type of tank is filled with angled plates or profile inserts, which are characterized by a high sedimentation surface. In lamella settling tanks, the sedimentation process occurs gravitationally and takes place in a laminar flow field between parallel plates.

In the studies, before and after the disintegration process, the following parameters of total solids (TS), volatile solids (VS) capillary suction time (CST) were determined according to applicable standards [24, 25, 26]. In the sludge liquid, however, changes in the COD value were measured with the Merck cuvette test method [27].

The ultrasonic disintegration process of sludge was carried out using the ultrasonic disintegrator VCX-500 Vibra Cell Ultra Sonic Processor Sonics&Materials Inc (Fig. 2). Sludge samples with a constant volume of 500 cm^3 were subjected to disintegration. The test stand consisted of a vibration generator with a power of 500 W, a head equipped with an energy concentrator (sonotrode) with a diameter of 19 mm, and a sound-absorbing chamber. This equipment allows the process to be carried out at an ultrasonic wave frequency of 20 kHz and a vibration amplitude adjustable in the range

Fig. 1. Post--coagulation sludge from water treatment plant.

Fig. 2. Ultrasonic disintegrator Sonics Vibra-cell VCX 500.

from 20 to 100% of the nominal amplitude of the tip (60 µm).

Post-coagulation sludge disintegration tests were carried out for vibration amplitudes equaled 30%, 40%, 50%, 60%, and for process durations equaled 2, 4, 6, 8, 10 minutes.

Results and discussion

The tested post-coagulation sludge had a total solids (TS) content of 0.04% and a very high hydration of 99.96%. The volatile solids content was 33.3% TS, and the mineral solids was 66.7% TS. The COD value related to the concentration of organic compounds in the sludge liquid was only 19 mg/dm^3.

Moreover, the post-coagulation sludge in the CST test showed good filtration properties, with a value of 53 seconds.

After the disintegration process, the total solids content increased slightly to 0.05% for an amplitude of 30% and sonication time of 4, 6, 8, and 10 minutes and to 0.06% for higher amplitudes - 40, 50, and 60% (Fig. 3). The use of ultrasonic waves did not cause significant changes in the content of volatile solids (Fig. 4), whose value changed from 33.3 % TS to 45.5 % TS for an amplitude of 30% depends of time of disintegration. However, the volatile solids content changed from 37.5 to 47.7 % TS and from 38.2 to 47.5 % TS depending on time exposure to ultrasonic waves, respectively amplitudes of 50% and 60%.

Analyzing the results obtained in the capillary suction time test (CST), one can notice its decrease with increasing disintegration time for each of the tested amplitudes (Fig. 5). CST in the case of using 30% amplitude and the shortest sonication time was reduced to 48 seconds and 32 seconds for 10 minutes. The use of higher amplitudes improved the filtration properties of the tested sludge, and a CST of 26 seconds was obtained. Generally, increasing the disintegration time lowers the CST. Based on the results obtained, it can be concluded that using ultrasound improves the filtration properties of the post-coagulation sludge. The capillary suction time determines the rate at which the sludge releases liquid. A low CST indicates that the sludge releases its water content very easily. The higher the CST, the more difficult the sludge is to dewater. According to Dewil et al. [28], the capillary suction time for sludge with good dewaterability is about 20 s.

Measuring COD in the overlying liquid allows you to assess the degree of release of organic intracellular compounds (such as proteins, enzymes, and fats) from the microorganisms that make up the activated sludge. This is possible by the action of ultrasound on their cell walls. In the case of the tested post-coagulation sludge (before the disintegration process), a low COD concentration of 19 mg/dm^3 is visible. The use of ultrasonic disintegration using amplitudes of 30-50% did not result in a significant increase in COD. A visible increase in COD (by 17-26 mg/dm^3) was obtained for an amplitude of 60% (Fig. 6.). Only amplitudes at this level and higher can break down the cell walls of microorganisms. A slight increase in COD may also indicate a small number of microbial cells present in the sludge and, consequently, the release of small amounts of intracellular compounds into the overlying liquid. Activated sludge is composed mainly of a suspension of microorganisms, unlike post-coagulation sludge from drinking water treatment.

In addition, changes in the structure of the sludge tested were visually assessed. The sludge that was not disintegrated was characterized by a loose floc structure (Fig. 7). The use of the ultrasonic disintegration process loosened and broke up the sludge flocs. As a result of sonication, the sludge was characterized by a very loose, fine structure, practically devoid of large clusters of flocs, regardless of the amplitude used.

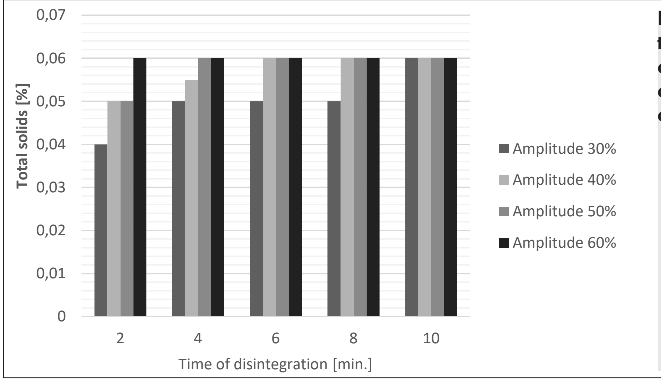

Fig. 3. Changes in the total solids content depending on the amplitude and time of disintegration.

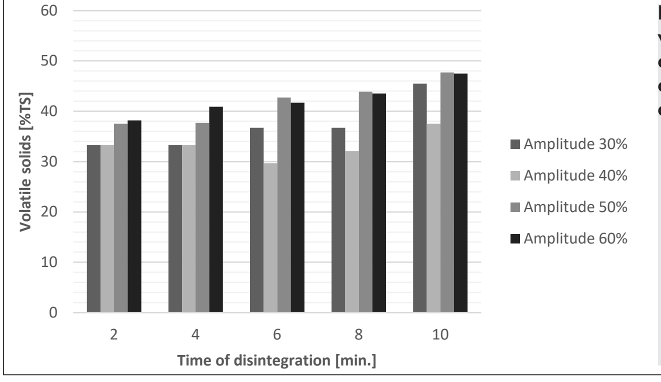

Fig. 4. Changes in the volatile solids content depending on the amplitude and time of disintegration.

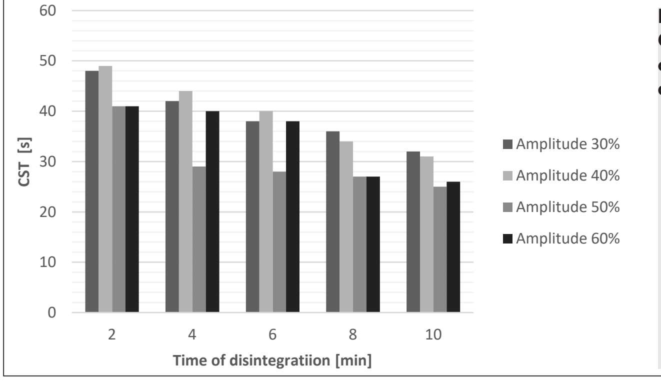

Fig. 5. Changing the CST value depending on the disintegration amplitude and time.

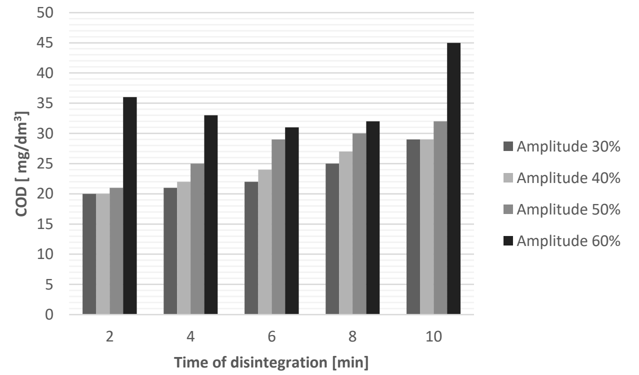

Fig. 6. Changes the COD value depending on the amplitude and time of disintegration.

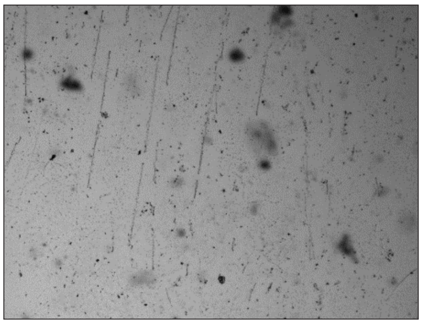

Fig. 7. Microscopic image of the post-coagulation sludge before the disintegration process.

Summary and conclusions

The article presents the results of research on the use of the ultrasonic disintegration process in the case of post-coagulation sludge from a water production plant. The literature contains information on the disintegration process of municipal sewage sludge, and in particular, there is no information on ultrasonic disintegration. Scientific publications mainly focus on disintegration, used mainly to destroy cell membranes and lyse the cells of microorganisms that make up sewage sludge. Therefore, it is justified to research post-coagulation sludge.

Before the disintegration process, the sludge was characterized by a very high hydration of 99.96% and a low total solids content of 0.04%. The use of ultrasound did not cause significant changes in this parameter. After the disintegration process, the total solids content increased slightly to 0.05% for an amplitude of 30% and 0.06% for higher amplitudes - 40, 50, and 60%. Subjecting the sludge to ultrasonic disintegration resulted in an increase in the content of volatile solids, whose value changed from 33.3 % TS to 45.5 % TS for an amplitude of 30%, 37.5 %TS for an amplitude of 40%, 47,7 %TS for amplitude 50% and 47,5 %TS for amplitude 60% after 10 minutes sonification.

Based on the obtained results of the disintegration of post-coagulation sludge with ultrasonic waves, it can be concluded that this method is effective. During the disintegration process, the filtration properties of the sludge were improved due to the destruction of microbial cells and the release of biologically bound water. The disintegration efficiency is proven with lower capillary suction time (CST). The lower the CST value, the more susceptible the sludge is to the dewatering. The use of 30% amplitude allows the CST value to be reduced from 53 to 32 seconds. The test results indicated that the effectiveness of the disintegration process depended on the amplitude value, i.e., on the time of exposure of sludge to sonification. The best result was obtained with a 10-minute exposure time and 50% amplitude, followed by a CST of 25 seconds.

During the ultrasonic waves, the cell membrane of microorganisms is destroyed. As the cell breaks down, intracellular water and organic compounds are released. The release of organic compounds translates into an increase in COD in the supernatant liquid. The COD value increased from 19 mg/dm^3 before the disintegration process to 20 – 45 mg/dm^3 after the process, depending on the duration and amplitude.

The performed microscopic analysis showed that the disintegration process resulted in the breakdown of sludge flocs. The sludge after the process was characterized by a very loose structure, regardless of the applied amplitude and process duration.

Post-coagulation sludge formatting from surface water treatment processes is characterized by high hydration. The application of disintegration using ultrasonic waves to condition these sludge improves their filtration properties. Changing these properties can improve the efficiency of their mechanical dewatering.

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