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The effect of ultrasonic disintegration on sewage sludge conditioning

Paweł Wolski

Czestochowa University of Technology, Faculty of Infrastructure and Environment, Institute of Environmental Engineering, Brzeznicka 60a, 42-200 Czestochowa, Poland, email: pwolski@is.pcz.czest.pl

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ABSTRACT

The most important process of sewage sludge treatment is to maximally reduce its volume. During the process of thickening by removing free water or water released through conditioning, the volume of sludge is reduced without losing its liquid consistency. Gravity water is removed in the process, with a maximum content of solids of 12%. Gravity thickening occurs through sedimentation of sludge particles suspended in the liquid and their compression using gravity forces. The aim of the study was to determine the efficiency of the released free water depending on operation time and the amount of the sonication energy supplied. The effect of stabilization time on the content of released free water was also determined. The dispersion effect of the ultrasound field had a very positive effect on the efficiency of sewage sludge thickening. Single fragmented sludge flocs were better packed and released free water. The increase in thickening efficiency was directly proportional to the time and wavelength of the ultrasound field. The best sedimentation effects were observed in the first 30 min of the thickening process, with the lowest volumes in relation to thickening time and the highest rates of 1.93 cm/min (energy density 0.20 W/ml), 2.5 cm/min (energy density 0.28 W/ml), 2.63 cm/min (energy density 0.37 W/ml), 2.83 cm/min (energy density 0.46 W/ml) and 2.9 cm/min (energy density 0.58 W/ml) found for the 10th minute. A very positive effect on the efficiency of free water release was also observed when sewage sludge was subjected to stabilization. The highest increase in thickening was recorded for the highest wave intensity (energy density 0.58 W/ml), with the lowest volume values (25 ml) recorded after 4 d of the fermentation process in flasks and 30 min of thickening.

Keywords: Sewage sludge; Thickening; Disintegration; Dewatering

1. Introduction

The most important process of sewage sludge treatment is to maximally reduce its volume [1,2]. Water content in sewage sludge depends on sludge consistency, which has a direct effect on their hydraulic capacity in pipelines [3,4]. By removing free water or water released through conditioning during thickening, the volume of sludge is reduced without losing its liquid consistency. Thickening occurs through the removal of gravity water, with a maximum content of solids of 12%. During dewatering, the semi-bound water is removed, reaching a maximum of 50% water content [5–7].

Gravity thickening occurs through sedimentation of sludge particles suspended in the liquid and their compression using gravity forces. The interaction between settling particles depends on the density, shape and size, viscosity and density of the liquid, the position of individual particles in relation to each other and the direction of sedimentation, as well as the velocity of particles in relation to the liquid at infinite distance and the torques of particles in relation to their own axes. During the sedimentation, fine particles combine into larger agglomerates through coagulation or flocculation [8,9].

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The factor that improves coagulation efficiency is the use of conditioning with its appropriate parameters. The benefits of the effect of the ultrasonic field on sewage sludge dewatering were studied by Feng et al. [10]. In their study, the researchers used the energy dose from 0 to 35,000 kJ/kg d.m. The research showed that low energy doses below 4.400 kJ/kg d.m. improved sludge dewatering, while a decrease in sludge dewaterability was found for higher energy doses. The optimal amount of energy for which the most favorable results of sludge dewatering were obtained was 800 kJ/kg d.m.

Zhu et al. [11] carried out the research on the use of ultrasound, cationic polyelectrolytes and structure-forming material in improving water removal from sludge. The use of the above combination improved dewatering of sludge with respect to raw sludge. Optimal sonication conditions were 0.3 W/ml for 12 s at an ultrasonic frequency of 22 kHz, while the doses of structure-forming material and polyelectrolyte were 50.0% by weight and 20 mg/L respectively, resulting in the shortest filtering time of 43 s and the lowest filter cake humidity of 62.22%.

Meng et al. [12] examined the sludge from water treatment subjected to the exposure to the ultrasonic field under variable conditions, using two ultrasonic processors, four frequencies (25, 40, 68 and 160 kHz) and four levels of energy density (0.03, 1, 3 and 5 W/ml). The results showed that the dewaterability of the sonicated sludge improved at low energy densities (0.03 and 1.0 W/ml), with optimal sonication time of up to 10 min. For higher frequencies (up to 160 kHz) with an energy density of 0.03 W/ml, an improvement in dewaterability was also observed. In the case of higher energy densities of 3.0 and 5.0 W/ml, sludge dewaterability deteriorated regardless of the duration of the exposure to ultrasound waves. The deterioration of dewaterability was closely related to the significantly reduced size of flocs, dissolving of protein and polysaccharides and zeta potential of the sonicated sludge flocs.

Coagulation occurs as a result of the joining of individual particles in agglomerates by adding a coagulant that lowers the electrokinetic potential of particles, facilitating bringing them closer to the distance of the effect of van der Waals forces. As noted by Błażejewski [13], if particles are closer than a distance of 1 nm, where the interaction energy is the lowest, their connection is permanent. The added coagulant neutralizes the particle charge and reduces the electrostatic deflection, resulting in easily falling agglomerates. Crowley [14] observed that pairs of particles on the main axes fall faster than single particles, whereas pairs shifted towards the main axes fall diagonally, forming agglomerates. Flocs of suspension are formed from a combination of smaller elements with various shapes in agglomerates of quite a diversified structure. Chung and Lee [15] developed an active sludge floc model in which the solid phase with a density of 1,450 kg/m^3 occupies only 1%–2% of the floc volume. The porosity of such a floc does not exceed 64%. The combination of solids and liquids forms a suspension. The colloidal suspension is formed by particles with dimensions ranging from 1 to 500 nm. When the particle size of the dispersed phase is between 1 to 100 nm, the suspension is called a colloidal system that is very slowly separated into individual phases during a gravity thickening process.

In addition to the effect on thickening and dewaterability, the use of ultrasonic energy is also important for the fermentation process and biogas production. Zieliński et al. [16] studied the effect of an innovative ultrasonic string disintegrator used for pre-treatment of sewage sludge on the efficiency of the methane fermentation process. The volume of biogas produced ranged from 0.194 ± 0.089 dm^3/g o.d.m. at 5.0 g o.d.m./dm^3 load and ultrasonic power of 50 W to 0.315 ± 0.087 dm^3/g o.d.m. at 4.0 g o.d.m/dm^3 load and ultrasonic power of 125 W. The study showed a positive effect of sewage sludge sonication on the percentage content of methane in biogas. The exposure of sewage sludge at the ultrasonic power of 125 W increased the methane content of biogas to 68.3% ± 2.5% at a digester load of 3.0 g o.d.m./dm^3.

In Błażejewski [13], demonstrated that sedimentation in Newtonian fluids has a different course compared to non-Newtonian liquids. Suspensions in a Newtonian fluid with volume concentrations of above 0.1–0.3 behave like Newtonian fluids, and above these concentrations, they show rheological properties. In non-Newtonian fluids, the behavior of suspensions depends, among others, on the shear rate [17–19].

The study aimed to determine the efficiency of the released free water depending on operation time and the amount of the sonication energy supplied. The effect of stabilization time on the content of released free water was also determined.

2. Substrate and methodology

A substrate for the study was excess sewage sludge after the secondary settler obtained from a mechanical-biological sewage treatment plant with a capacity of 90,000 m^3/d (which corresponds to 314835 PE) collecting both municipal and industrial wastewater. The sludge was characterized by the following parameters: a dry matter of 11.0 ± 2.4 g/L, dry organic matter of 7.3 ± 2.4 g/L, capillary suction time of 24 ± 2 s, the initial water content of 98.9%, the final water content of 84.8%, specific sludge resistance of 2.96 × 10^{12} m/kg. Dry mass content and initial water content of sludge were determined based on the standard PN-EN-12880. Capillary suction time was measured using the Baskerville and Galle methodology, which is based on the measurement of time of transition of the frontal boundary layer of filtrate as a result of the effect of suction forces as described in the paper (Whatman 17). The result presented in the study was the time of absorption of the sludge by the filtration paper between the rings with a diameter of 32 and 45 mm.

In the first stage of the study, excess sludge was subjected to sonication, and the amount of free water release from the sludge was then tested. The sonication process was conducted in static conditions in five test cycles for selected values of vibration amplitude: 7.88 μm (20% amplitude); 15.77 μm (40% amplitude); 23.65 μm (60% amplitude); 31.54 μm (80% amplitude), and 39.42 μm (100% amplitude). The adopted vibration amplitudes corresponded to the intensity of the ultrasound wave of 1.6, 2.2, 2.7, 3.2 and 3.8 W/cm^2, which corresponded to an energy density of 0.20, 0.28, 0.37, 0.46 and 0.58 W/ml. The research used a dose of energy from 0 to 38,700 kJ/kg dry matter.

In the second stage, after previous conditioning (so-called pre-conditioning) and addition of inoculum (10% of fume cupboard sludge), excess sludge was subjected to the anaerobic fermentation process. Pre-conditioning process was also performed under static conditions for selected vibration amplitudes: 23.65 μm (60% amplitude); 31.54 μm (80% amplitude), and 39.42 μm (100% amplitude). The adopted vibration amplitudes corresponded to the ultrasound wave intensity of 2.7; 3.2 and 3.8 W/cm^2 (0.37; 0.46; and 0.58 W/ml). Sludge conditioning was carried out using the ultrasound field for 600 s. The stabilization process was carried out in laboratory flasks for 10 d in mesophilic conditions.

According to Śliwiński [20], the acoustic field can be described by energy values that describe the transport of energy through waves. The amount of energy which is transported by the acoustic waves over time of 1 s per area of the surface which is perpendicular to the direction of wave propagation is termed sound intensity. It is given by the equation:

$$I = \frac{N}{S} \tag{1}$$

where N is the power transported by the waves, W; S is the surface of wave propagation, m^2.

The process of sewage sludge sonication used ultrasound processor Sonics VCX-1500 with a maximal power output of 1,500 W (Fig. 1). The frequency of ultrasound field vibration was 20 kHz whereas maximal wavelength for the amplitude of 100% was 39.42 μm. The device is used to transform electricity into mechanical energy supplied to the titanium tip in the form of a wave. The amount of energy supplied to the system was read after each measurement. The volume of the samples used for sonication was 500 cm^3.

Processor VCX-1500 is a technologically advanced, high-intensity ultrasonic processor for high and low volume applications. It can safely process a wide variety of organic and inorganic materials in applications such as cell disruption, sample preparation, homogenization, disaggregation and sonochemical reactions. The system can vary the power output and constantly monitor both power (Watts) and energy (Joules). The microprocessor control with real-time display gives digital accuracy and reproducible control of the set and run parameters.

Fig. 1. Ultrasonic processor VCX-1500.

The stabilization process was performed in glass flasks that represented models of fermentation chambers. The sludge samples were placed in 10 laboratory flasks with a volume of V = 0.5 L. In order to maintain a constant process temperature (mesophilic conditions), the flasks were placed in a laboratory thermostat at 37°C for 10 d. In order to prevent air access, the flasks were plugged with a plug equipped with a liquid-column gauge to allow the release of the biogas produced. The contents of the flasks were stirred using magnetic stirrers, thus removing the resulting fermentation skin and preventing the overload with contamination. Every day one of the flasks was removed, and determinations were performed.

Gravity thickening was performed to determine the capability to release free water from sludge [21]. The sewage sludge samples were poured into measuring cylinders with a volume of 100 cm^3, where the sludge particle sedimentation was observed at specific time intervals. The readings of the separating layer of thickened sludge from free water were recorded after 5, 10, 15, 20, 25, 30, 45, 60, 90 and 120 min. The determination of thickening curves as the main sludge thickening test allowed for the determination of the amount of free water release from disintegrated sewage sludge.

3. Results and discussion

Proper removal of excess water from sewage sludge has an effect on the effectiveness of the fermentation process. The purpose of the free water release test is to determine the effect of conditioning and fermentation on the capability to release water. Removing excess water from the sludge also reduces process costs. Sewage sludge pre-conditioned with the ultrasound field at various ultrasound wave intensities and exposure times was studied.

The use of the ultrasound field energy in the preparation of sewage sludge involves energy costs, with its demand increasing with the time of ultrasonic wave propagation and wavelength. A positive effect of the ultrasound field on the final effect of free water release was observed for each applied wavelength. Similar research on the application of ultrasonic energy in sewage sludge conditioning was conducted by Feng et al. [10], Zhu et al. [11], and Meng et al. [12]. These authors conducted research on the effect of ultrasonic sonication on sewage sludge dewatering, while in the case of Meng et al. [12], research was conducted on sludge from water treatment. The data shown in Fig. 2 show that non-conditioned sludge (sonication time 0 min) did not release free water despite being thickened for 30 min. The propagation of the ultrasound wave accelerated the process of free water release, which resulted from the dispersion of sludge flocs and, consequently, better "packing" allowing for releasing free water. It was also observed in studies conducted by these researchers that when low energy doses were applied (less than 4,400 kJ/kg d m.), sludge dewaterability improved, while deterioration of sludge dewatering capacity was found for higher energy doses. At the shortest sonication time (0.5 min) the energy demand was the lowest depending on the amplitude used. At a wave intensity of 1.6 W/cm^2, the (energy density was 0.20 W/ml), and the sludge volume remained unchanged (sedimentation rate was 0 cm/min) (Fig. 2a). As a result of

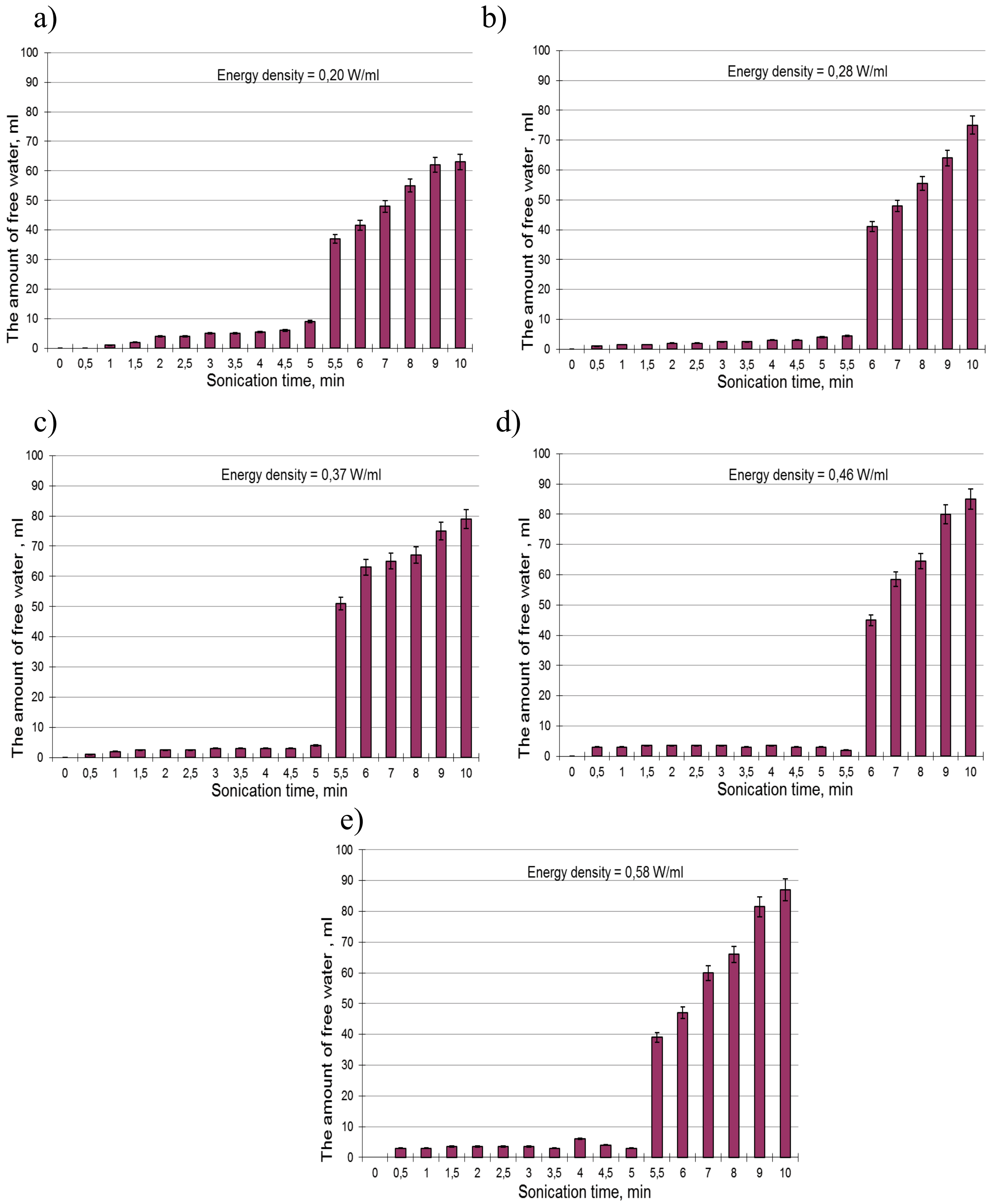

Fig. 2. Amount of free water released from the sewage sludge disintegrated with the ultrasound field (a) energy density 0.20 W/ml, (b) energy density 0.28 W/ml, (c) energy density 0.37 W/ml, (d) energy density 0.46 W/ml, and (e) energy density 0.58 W/ml; sludge time 30 min.

an increase in wave intensity to 3.8 W/cm^2 (energy density was 0.58 W/ml), a 3% decrease in the volume of sludge was recorded (Fig. 2e). The dose of energy used was 1,563 kJ/kg dry matter. Application of higher amplitudes and time of ultrasound wave propagation allowed for further acceleration of the process. For a 20% amplitude, the energy density was 0.20 W/ml, whereas, for a 100% amplitude, the energy density was 0.58 W/ml.

The use of longer sonication times and higher wave intensities improved the efficiency of water separation from sewage sludge. The most noticeable tendency of the effect of the conditioning factor on the efficiency of water release for each of the amplitudes applied was observed after the fifth minute of sonication (Fig. 2). In the following minutes of exposure to the ultrasound field, the downward trend was more and more noticeable, with the highest values of released water recorded in the 10th min. Also, research conducted by Meng et al. [12] showed that the drainage of sonicated sludge was improved at low energy densities (0.03 and 1.0 W/ml), with an optimal sonication time of up to 10 min.

The effect of sonication time on the dispersion of sludge flocs was not evaluated in the study. The sonication time of 5 min was the time for which a significant increase in the amount of released free water was found despite several repetitions of the tests. This could have been caused by the nature of the sludge being tested and its susceptibility to the exposure to ultrasonic waves. The increase in ultrasonic wave intensity led to the intensification of the release of free water at any increase in the ultrasound wave intensity. Comparison of the sludge treated with ultrasonic wave intensity of 3.8 and 1.6 W/cm^2 (energy density 0.58 and 0.20 W/ml) at 10 min sonication time revealed that the amount of free water increased by 23 ml. Application of the ultrasound field wave intensity at the level of 1.6 W/cm^2 and the propagation time of 10 min (energy density 0.20 W/ml) led to a significant (42%) water release compared to non-conditioned sewage sludge. The dose of energy used was 11,450 kJ/kg dry matter. Further extension of the wavelength of the ultrasound field resulted in subsequent increases in energy demand, with its value correlated with the amount of released free water. Despite high energy expenditure, the value of the final volumes was 87% lower than the value of not conditioned by ultrasonic field sludge. The thickening rate after 30 min of sedimentation in the compaction zone was 2.9 cm/min, which, despite the high energy demand, greatly improves the efficiency of the thickening process (Table 1). The separation of the two phases during the thickening process was very noticeable, especially using the active exposure to ultrasounds, where the separation of solids (sludge) and supernatant liquor was very intensive, as evidenced by the results obtained. Unfortunately, photographic documentation was not conducted for the observed and recorded effects. In research conducted by Zhu et al. [11], the optimal sonication conditions were 0.3 W/ml for 12 s at an ultrasound frequency of 22 kHz. Zhu et al. [11] conducted research on the combination of the use of ultrasound, cationic polyelectrolytes and structuring material in improving the removal of water from sediments.

The high intensity of the thickening process, and consequently, the high intensity of free water release in the first minutes is also confirmed by the calculated thickening rates for sewage sludge conditioned with the ultrasound field (Tables 1 and 2). Thickening rates after 30 min for each of the wavelengths tested were much higher compared to the 120 min thickening time. They were 1.933 cm/min (energy density 0.20 W/ml), 2.5 cm/min (energy density 0.28 W/ml), 2.633 cm/min (energy density 0.37 W/ml), 2.833 cm/min (energy density 0.46 W/ml), respectively. The highest thickening rate of 2.9 cm/min was recorded for sewage sludge conditioned with the ultrasound field (energy density 0.58 W/ml, sedimentation time 30 min) (Table 1). For energy density 0.58 W/ml and sedimentation time of 120 min, the thickening rate was 0.75 cm/min (Table 2) (the value of the sedimentation rate decreased compared to the rate for the 30 min sedimentation time, which is consistent with the shape of the thickening curve, with the sedimentation rates decreasing with the thickening time).

Table 1
Thickening rates for sonicated sewage sludge after 30 min of sedimentation

Exposure time with the ultrasonic field, min																
0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10
Sludge thickening rate, cm/min (energy density 0.20 W/ml)																
0	0	0.033	0.067	0.183	0.233	0.1	0.15	0.167	0.183	0.3	1.223	1.383	1.6	1.833	2.067	1.933
Sludge thickening rate, cm/min (energy density 0.28 W/ml)																
0	0.033	0.05	0.05	0.067	0.067	0.067	0.083	0.1	0.083	0.117	0.15	1.367	1.6	1.85	2.133	2.5
Sludge thickening rate, cm/min (energy density 0.37 W/ml)																
0	0.033	0.1	0.083	0.083	0.083	0.133	0.067	0.083	0.083	0.1	1.7	2.267	2.167	2.233	2.5	2.633
Sludge thickening rate, cm/min (energy density 0.46 W/ml)																
0	0.1	0.1	0.117	0.117	0.083	0.117	0.067	0.117	0.1	0.083	0.067	1.5	1.95	2.15	2.667	2.833
Sludge thickening rate, cm/min (energy density 0.58 W/ml)																
0	0.1	0.1	0.117	0.117	0.083	0.117	0.067	0.2	0.083	0.067	1.3	1.567	2	2.2	2.717	2.9

Table 2
Thickening rates for sonicated sewage sludge after 120 min of sedimentation

Time of exposure to the ultrasonic field, min																
0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	7	8	9	10
Sludge thickening rate, cm/min (energy density 0.20 W/ml)																
0	0	0.058	0.067	0.117	0.142	0.108	0.1	0.117	0.133	0.192	0.458	0.392	0.467	0.508	0.596	0.567
Sludge thickening rate, cm/min (energy density 0.28 W/ml)																
0	0.05	0.05	0.025	0.058	0.042	0.033	0.063	0.058	0.054	0.108	0.092	0.483	0.45	0.533	0.583	0.642
Sludge thickening rate, cm/min (energy density 0.37 W/ml)																
0	0.058	0.071	0.075	0.067	0.083	0.1	0.058	0.075	0.075	0.167	0.5	0.467	0.583	0.608	0.667	0.675
Sludge thickening rate, cm/min (energy density 0.46 W/ml)																
0	0.067	0.079	0.104	0.1	0.071	0.113	0.042	0.058	0.075	0.067	0.092	0.467	0.533	0.583	0.7	0.725
Sludge thickening rate, cm/min (energy density 0.58 W/ml)																
0	0.067	0.079	0.104	0.1	0.071	0.113	0.042	0.167	0.067	0.142	0.458	0.5	0.608	0.642	0.692	0.75

A further increase in the release of free water was observed when sewage sludge was exposed to sonication and then stabilization. Sonication and stabilization of sludge do not only intensify the release of free water but, as noted by Zieliński et al. [16], they are also important for the fermentation process and biogas production. Intensification of the release of free water for non-conditioned sludge was found after the 6th day of stabilization (Fig. 3a). After 30 min of thickening on the 7th day of the process, its amount was 47 ml, which translated into ca. 50% reduction in volume.

An increase in the thickening efficiency was observed already in the first days of the fermentation process, when sewage sludge was exposed to ultrasound field energy (Figs. 3b–d). The prepared sludge showed a rapid decrease in volume at each of the applied wavelengths of the ultrasound field. For example, on day 3 of stabilization, the amount of free water was 78 ml (energy density 0.58 W/ml, sedimentation time 30 min) (Fig. 3d). The high thickening rate (2.4 cm/min) is also a confirmation of this result. Also, for other applied wavelengths, water release was at a high level. On day 10 of fermentation, its volume was 75 ml (energy density 0.37 W/ml), 60 ml (energy density 0.46 W/ml) and 79 ml (energy density 0.58 W/ml). Water from fermented sludge, pre-conditioned using the ultrasound field was the most intensively separated at the energy density 0.46 and 0.58 W/ml, for which the smallest volume and the highest thickening rates were recorded (Fig. 3, Table 3). The thickening rates for sonicated sewage sludge after 120 min of sedimentation decreased (Table 4). It can be concluded that the tendency of water release was proportional to the fermentation time.

4. Conclusions

The energy of the ultrasound field, depending on its intensity, wavelength, exposure time and sludge characteristics, may have a dispersive or coagulating effect. The dispersion effect of the ultrasound field had a very positive effect on the efficiency of sewage sludge thickening, for an energy density

Table 3
Thickening rates for sonicated sewage sludge subjected to fermentation (after 30 min, sonication time 5 min)

Fermentation time, d										
0	1	2	3	4	5	6	7	8	9	10
Thickening rates for sewage sludge subjected to fermentation, cm/min										
0	0	0	0.067	0.117	0.167	0.167	1.567	1.833	2.1	2.067
Thickening rates for sonicated sewage sludge subjected to fermentation (energy density 0.37 W/ml)										
0.1	0.167	0.067	0.133	0.6	0.833	1	1.483	1.967	1.967	2
Thickening rates for sonicated sewage sludge subjected to fermentation (energy density 0.46 W/ml)										
0.083	0.267	1.333	2.033	2.233	2.2	2.367	2.4	2.467	2.5	2.5
Thickening rates for sonicated sewage sludge subjected to fermentation (energy density 0.58 W/ml)										
0.067	0.633	1.867	2.4	2.5	2.5	2.433	2.5	2.567	2.6	2.533

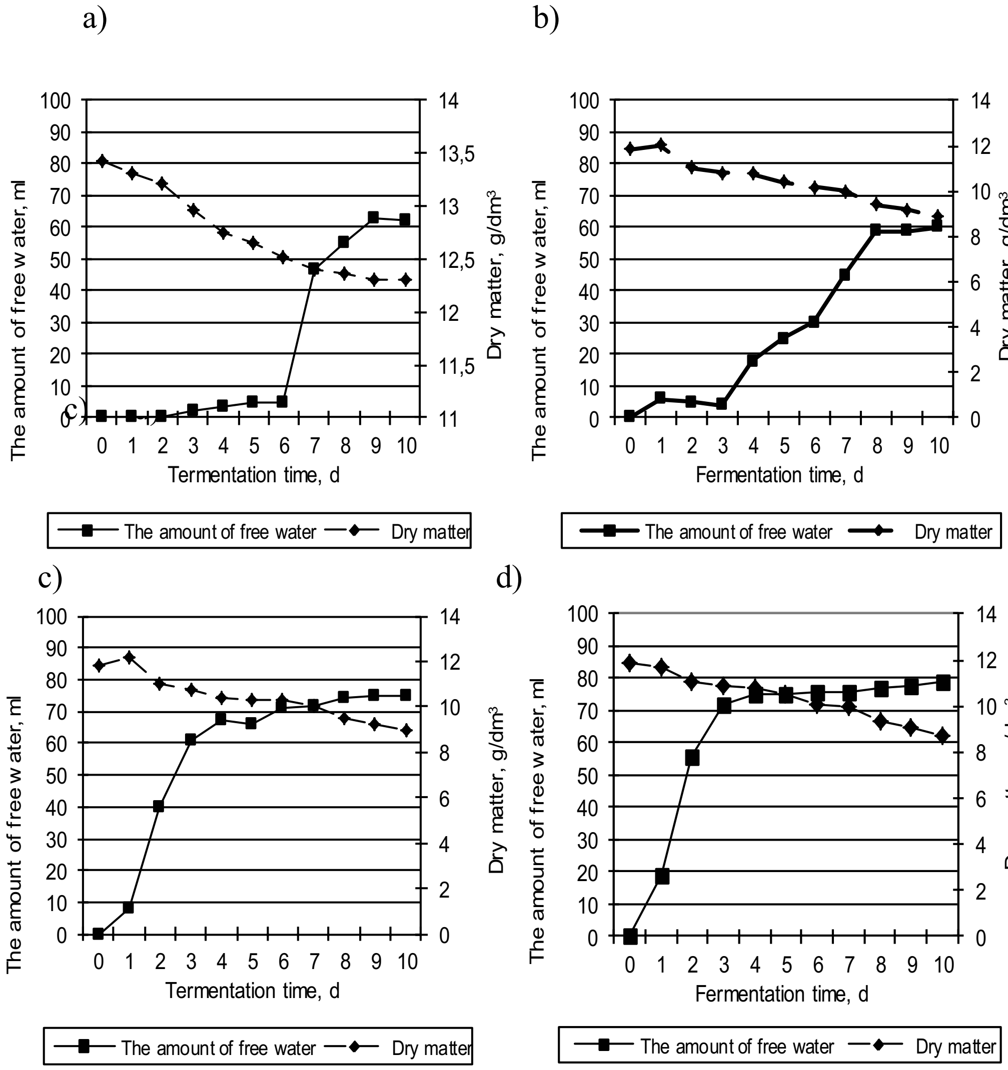

Fig. 3. Volume of free water and dry matter of sewage sludge formed during the stabilization process: (a) non-conditioned sludge, (b) sludge + ultrasound field 0.37 W/ml, (c) sludge + ultrasound field 0.46 W/ml, and (d) sludge + ultrasound field 0.58 W/ml; sedimentation time 30 min; sonication time 5 min.

Table 4
Thickening rates for sonicated sewage sludge subjected to fermentation (after 120 min, sonication time 5 min)

Fermentation time, d										
0	1	2	3	4	5	6	7	8	9	10
Thickening rates for sewage sludge subjected to fermentation, cm/min										
0	0.017	0.033	0.125	0.071	0.142	0.15	0.542	0.55	0.592	0.608
Thickening rates for sonicated sewage sludge subjected to fermentation (energy density 0.37 W/ml)										
0.167	0.05	0.042	0.117	0.267	0.35	0.5	0.533	0.567	0.558	0.567
Thickening rates for sonicated sewage sludge subjected to fermentation (energy density 0.46 W/ml)										
0.067	0.242	0.517	0.6	0.608	0.608	0.625	0.613	0.658	0.642	0.65
Thickening rates for sonicated sewage sludge subjected to fermentation (energy density 0.58 W/ml)										
0.142	0.35	0.558	0.638	0.667	0.65	0.633	0.65	0.65	0.654	0.675

of 0.20 to 0.58 W/ml, using an energy dose of 0 to 38700 J/kg dry matter. Single fragmented flocs were better "packed", releasing free water. A clear effect for each amplitude studied was observed in the 6th minute of exposure to the ultrasound field. The best sedimentation effect was observed in the first 30 min of the thickening process.

The positive effect of the initial modification of the stabilized sewage sludge was also observed during the thickening process. The highest increase in thickening was recorded for the highest wave intensity (0.58 W/ml), where the lowest volume values (25 ml) were recorded after 4 d of the fermentation process in flasks and 30 min of thickening. In addition to the applied wavelength of the ultrasound field, the increase in thickening efficiency was also affected by the time of initial sludge sonication. In the last few days of thickening in flasks, sewage sludge was thickened over twice better for initial conditioning for 10 min compared to non-conditional. On the 10th d of stabilization, the volumes were 19 ml (sludge conditioned by the ultrasound field for 10 min), 40 ml (sludge conditioned by the ultrasound field for 5 min) and 38 ml (non-conditional sludge). The improvement and positive effect of stabilization on the efficiency of the thickening of pre-conditioned sludge are also confirmed by the thickening rate.

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