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THE INFLUENCE OF ULTRASONIC DISINTEGRATION AIDED WITH CHEMICALS ON THE EFFICIENCY OF SEWAGE SLUDGE CENTRIFUGATION

The dewatering efficiency of sewage sludge during its centrifugation was assessed using two methods: sludge was either conditioned by chemicals (cement, ash, gypsum) or exposed to the ultrasonic field and conditioned by these chemicals. The overall goal of this research was to prove that the ultrasonic field energy and the chemical substances can change the structure of sewage sludge by increasing the size and the packing ability of particles, and at the same time the quantity of gravitational water present in sewage sludge. This improves the efficiency of sewage sludge dewatering. The efficiency of mechanical dewatering can be increased by combining the method of initial sonication with adding chemicals during sewage sludge conditioning. We observed an increase in the velocity of flocculation which was related to the dispersing effect of ultrasounds. The addition of chemically neutral substances led to more efficient thickening of sewage sludge conglomerates. During mechanical dewatering these conglomerates maintained more rigid structure with reduced compressibility which resulted in their elevated porosity at high pressures and improved the dewatering ability of sludge. This decreased final hydration and changed the distribution coefficient in reference to the parameters of unconditioned sewage sludge during dewatering.

1. INTRODUCTION

The ability of solid particles to bind water depends on the structure and properties of sewage sludge. The sewage sludge particles which form a flocculant structure bind water in a mechanical way posing difficulties during subsequent dewatering. Water present in sewage sludge is classified as volumetric water and water which is bound physically, physically and chemically, and also chemically. Osmotic and capillary bonds are typical of the water bound physically. These bonds retain water mechanically in the pores and capillaries of the structure. This water shows the properties typical of volumetric water despite the fact that it is influenced by the capillary forces. Sewage sludge containing

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a large amount of this water usually dewaters easily. However sewage sludge with a high content of physically and chemically bound water is very difficult to dewater. This type of sludge consists mainly of mineral particles with the amorphous structure and hydrophilic characteristics. Chemically bound water is most heavily retained in the surface of sludge solid phase in the form of crystallization and hydrostatic water. This type of water cannot be removed from sewage sludge during the process of dewatering. The heterogeneity of water present in sewage sludge and the volumetric ratios of different water types determine the susceptibility of sewage sludge to dewatering. Sewage sludge conditioning aims at transforming the physically and chemically, and also physically bound water into gravitationally free water [5]. The efficiency of sludge dewatering in the process of centrifugation is influenced by the size of particles, whereas the rate of filtration is affected by the particle size, shape and concentration [1], [10], [11]. During sedimentation and gravitational thickening, these floccules lose their individual properties and aggregate to form sludge described as the dispersing systems with quasi-homogeneous flocculant structure. The coherence and homogeneity of the structure are considered the macroscopic properties of sludge [6]. The microscopic tests showed the finely-dispersing character of the flocculant structure and defined the size of granular particles built in this structure [2]. The concept of the structure of floccules is based on the spatial distribution of coagulating particles in floccules and intermolecular forces. The energy of interactions between the particles in the floccules depends on the joint effect of the van der Waals and London forces and the potential of double layers [4], [7], [8]. The sludge floccules show unstable structure which leads to interrelations between the size and shape of floccules and the structural resistance and hydraulic interactions. In this context, the notion of the size of floccules is not easy to define without estimating the effect of hydrodynamic forces. The unstable structure of sludge indicates the necessity of determining the effect of gravitational and hydrodynamic forces on this structure [3]. Conditioning of sludge by the application of chemically inactive substances is conducted by adding, e.g., ash, gypsum or diatomaceous soil in the proper ratios. Although these substances do not change the physical and chemical properties of sludge subjected to conditioning, they facilitate the process of sludge dewatering [9]. The results of the coagulating effect of the ultrasonic field depend on the size of particles in the sonicated suspension and the frequency of sound. However, there is a specific range of sound frequency for a selected size of particles in which the coagulation of particles occurs. The active interactions of ultrasounds influence an increase in the ability to more efficient special packing of sludge particles subjected to sonication, in particular sludge with the rigid particle structure [3].

2. MATERIALS AND METHODS

The present research aimed at determining the effect of sewage sludge conditioning on the dehydration degree during dewatering. The following substrates were investigated: i) non-treated sludge (N), ii) sonicated sludge (UD), iii) sludge sonicated and conditioned by chemical substances (cement, ash and gypsum). The values of the rate of rotation (3000 and 5000 r.p.m. for 5 minutes) were determined experimentally. Five samples of well mixed sludge (ca 100 cm^3) were centrifuged at 3000 and 5000 r.p.m. for 5 minutes. Then, the supernatant and sludge were transferred to weighed evaporating dishes. The content of dry matter, hydration and separation coefficient of sludge were determined according to the standard laboratory procedures. The dose of chemically neutral substances (cement, ash, gypsum-components) was 0.5 g per 100 cm^3 of the sludge investigated. The parameters of ultrasound wave for sludge sonication were as follows: the amplitude A (A = 45 μm, A = 90 μm) and the exposition time t (t = 30, 60 and 90 s). For sewage sludge dewatering, the laboratory centrifuge MPW-6.15 (up to RCF 20380 × g) with a periodic mode, speed controller and centrifugation time was used. For sludge sonication, the ultrasound disintegrator UP 400S with the frequency of 24 kHz and the possibility of correcting both amplitude and sonication time was used. The experiments were done with waste activated sludge obtained from the municipal–industrial treatment plant Koniecpol, which receives wastewater from fibreboards factory. The quantity of industrial wastewater does not exceed 10% of the general quantity of municipal wastewater. Activated sludge suspension was sampled as the excessive sludge after thickening in secondary settling tank. The investigated sludge was characterized by the following parameters: hydration of 99.2%, dry matter of 8 g/dm^3, mineral substances content of 37%, organic substances content of 63%, and pH 6.9. The capillary suction time was t = 125 s.

3. RESULTS

The present research aimed at establishing the relationships between different conditioning methods used for sewage sludge and the effects of dewatering in the process of centrifugation at various rotational speeds (3000 r.p.m. and 5000 r.p.m). The exposition of sewage sludge to the ultrasonic field for a short time (30, 60 and 90 s) leads to the disturbances in the system equilibrium. This results in the dispersion and partial homogenization of the suspension. In most cases, sonochemical processes are responsible for the changes observed in the sewage sludge exposed to sonication. These processes are induced by cavitation and resonance. This results from the mechanical forces generated in the pulsating pores with the adequate sizes which are in resonance with the particular vibration frequency of waves passing through the sludge. The most beneficial results of the dewatering of sewage sludge exposed to the ultrasonic field were achieved at the amplitude of 90 μm and the longest exposure time of 90 s (figures 2 and 4), irrespectively of the values of the rotational speed. The maximum decrease in the final hydration by 3.0% in relation to the final hydration of non-treated sewage sludge was achieved for the sludge centrifuged at 5000 r.p.m. (figure 4).

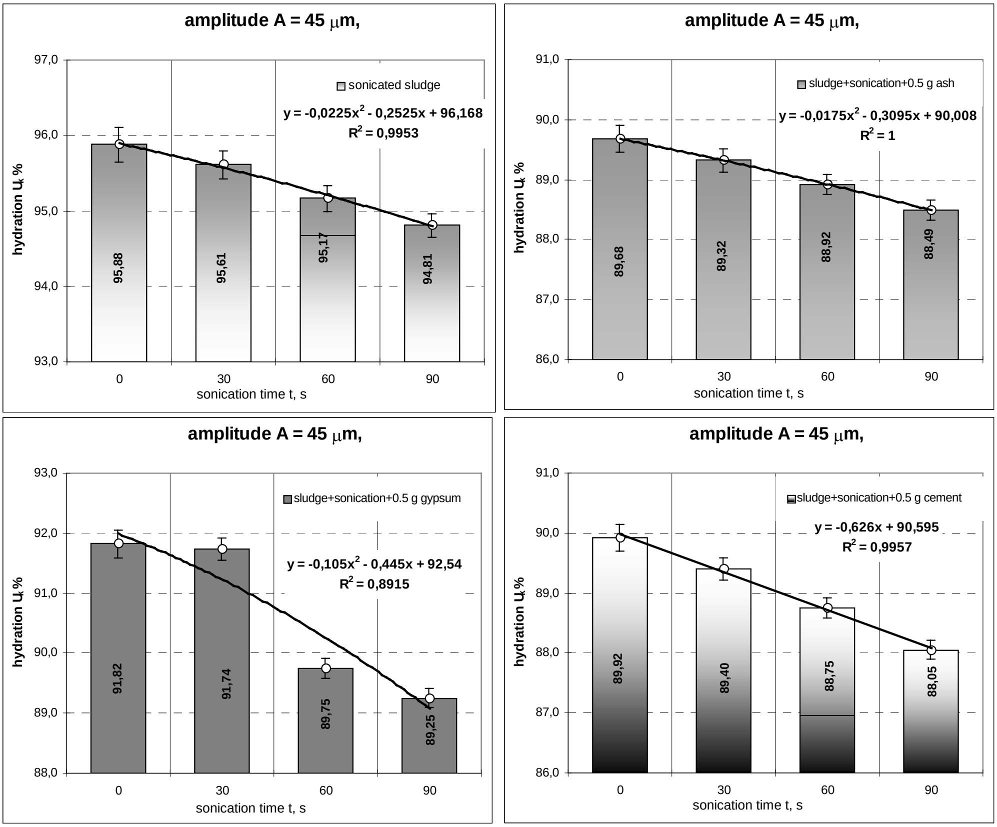

Fig. 1. Changes in the final hydration of sewage sludge exposed to the ultrasonic field at the amplitude A = 45 µm and selected components (the rotation rate of 3000 r.p.m.)

As for the sewage sludge exposed to the ultrasonic field and centrifuged at 3000 r.p.m., the hydration values were within 1% (figures 1, 3). With an increase in the amplitude applied and a prolonged exposure time, the effect of final hydration is magnified. The results obtained can be explained by the dispersing effect of the ultrasonic field which also facilitates packing of finer particles in the sludge layers. Far more advantageous effects in reducing final hydration of centrifuged sludge were achieved by adding various components (cement, gypsum, ash) and combining sonication with these components during conditioning. The most favourable effects in reducing a final hydration by 9% at the maximum were observed for sewage sludge subjected to conditioning with the ultrasonic field + cement (we observed similar results for the remaining components in figures 3, 4). At both rotation rates (3000 r.p.m. and 5000 r.p.m) the best effects were observed for the longest amplitude of 90 µm. Due to a prolonged exposure time, the final hydration of centrifuged sludge decreased. The results obtained with this method of sewage sludge conditioning could be influenced by the chemical substances that increased the sludge porosity. Due to the formation of more rigid structure of sludge, which enables high porosities to be maintained under the centrifugal force, the large quantities of water could be removed.

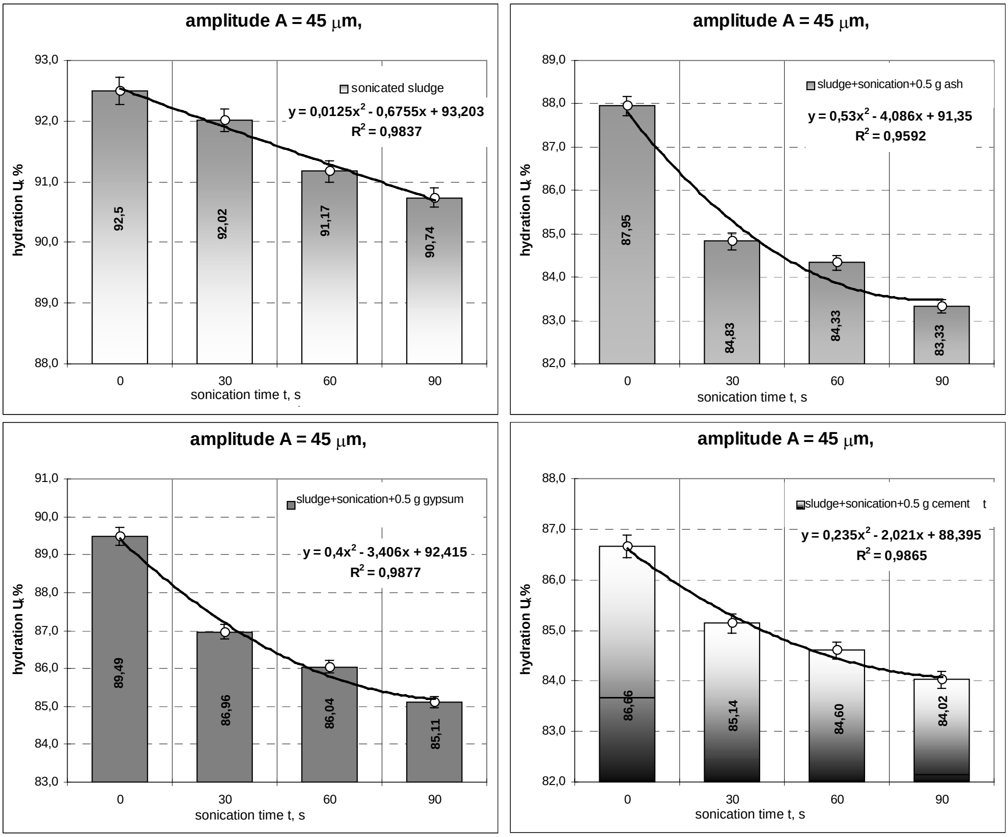

Fig. 2. Changes in the final hydration of sewage sludge exposed to the ultrasonic field at the amplitude A = 45 μm and selected components (the rotation rate of 5000 r.p.m.)

During centrifugation, the values of the distribution coefficient, i.e. the concentration of dry matter in reflux, changed. As a result of applying the ultrasonic field as an individual conditioning agent in sewage sludge conditioning (at the rotation rate of 5000 r.p.m.) a 97% separation of solid phase was achieved in most cases (see the table). Such an efficient separation of solid phase from water was possible due to a fine structure of the sludge obtained by applying ultrasounds as well as high value of the centrifugal force leading to an increase in the concentration of dispersed sludge particles. Fine particle sizes were responsible for more favourable conditions for packing. However, this did not significantly affect the dehydration degree of sewage sludge. At the rotation rate of 3000 r.p.m, where the values of the distribution coefficient reached 80%, the dehydration was less efficient (the table). The concentration of dry matter in the reflux increased during the application of initial sonication and selected components. The values of the distribution coefficient ranged from 75% to 81% (at the rotation rate of 3000 r.p.m.) and from 90% to 92% (at the rotation rate of 5000 r.p.m., the table). No clear relationship between the concentration of dry matter and the type of components, amplitude and exposure time was found. This may be due to the content of light particles of mineral substances in the selected components which are suspended in the sludge. These particles hardly precipitate even under the centrifugal force and form a suspension in the supernatant which in turn increased the concentration of dry matter.

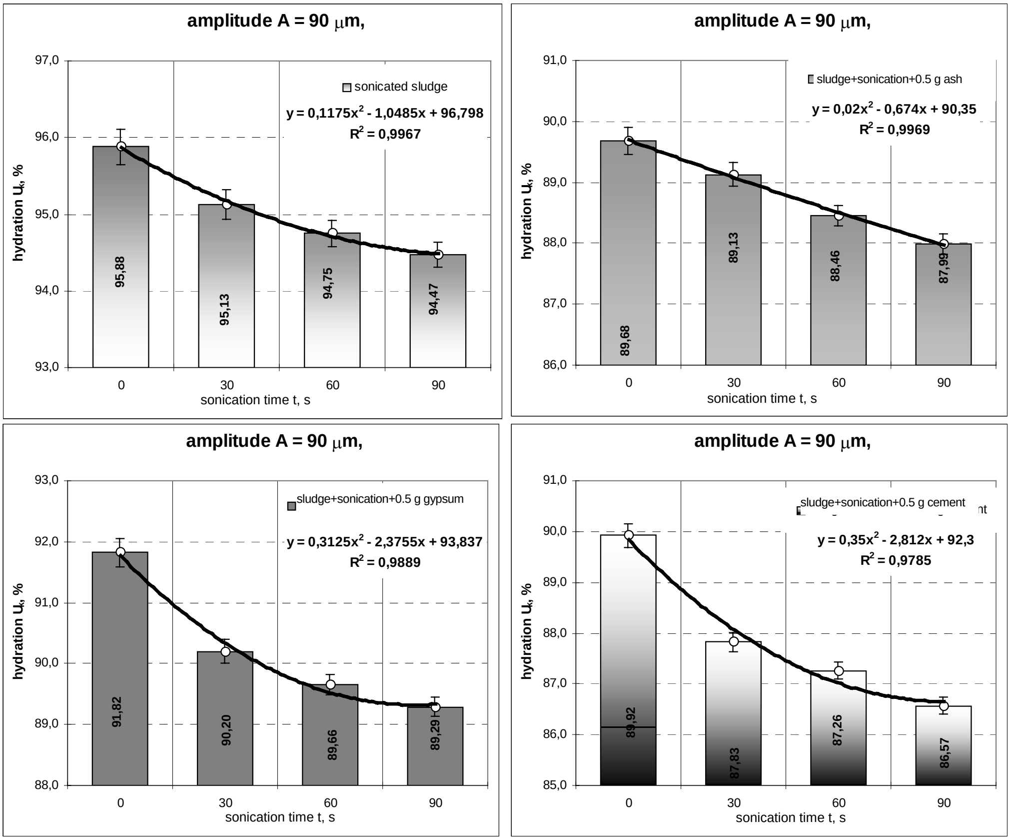

Fig. 3. Changes in the final hydration of sewage sludge exposed to the ultrasonic field at the amplitude A = 90 μm and the selected components (the rotation rate of 3000 r.p.m.)

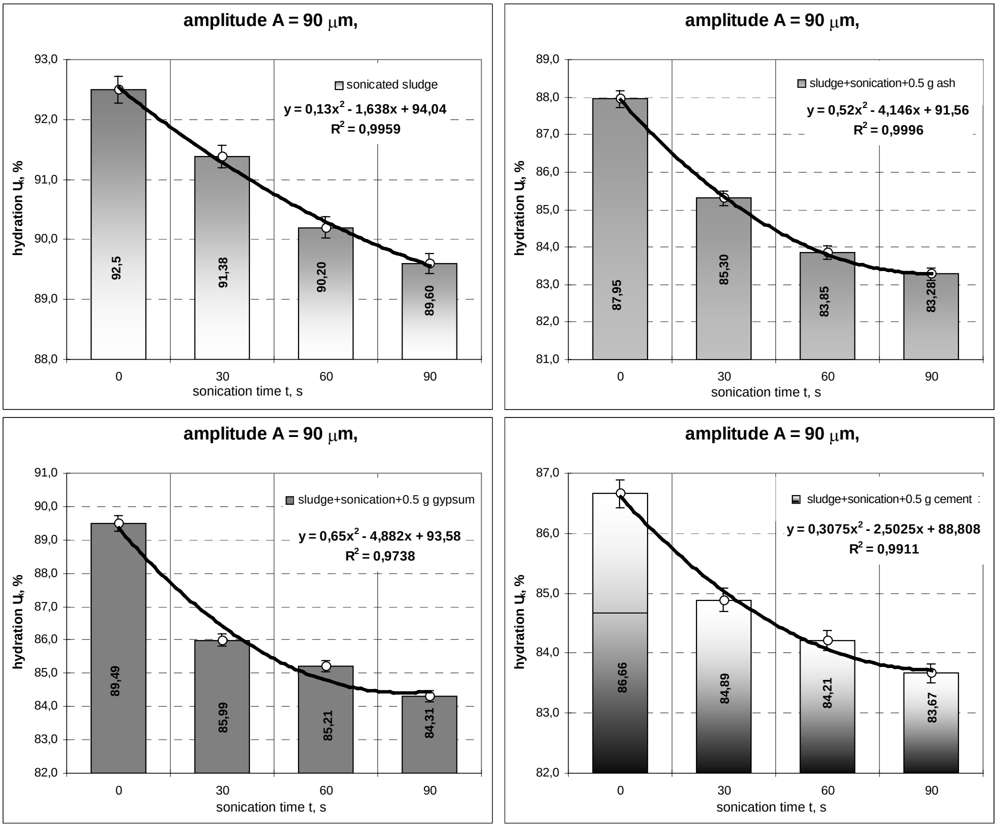

Fig. 4. Changes in the final hydration of sewage sludge exposed to the ultrasonic field at the amplitude A = 90 μm and selected components (the rotation rate of 5000 r.p.m.)

Table

Changes in the values of the distribution coefficient R for sewage sludge exposed to ultrasonic field and selected components

Sewage sludge condition	3000 r.p.m. Distribution coefficient R (%)	5000 r.p.m. Distribution coefficient R (%)	Sewage sludge condition	3000 r.p.m. Distribution coefficient R (%)	5000 r.p.m. Distribution coefficient R (%)
1	2	3	4	5	6
Sludge	97.5	99.0	Sludge + 0.5 g ash	78.9	91.5
Sludge + UD*, A = 45 μm, t = 30 s	90.9	97.7	Sludge + UD, A = 45 μm, t = 30 s + 0.5 g ash	78.0	89.9
Sludge + UD, A = 45 μm, t = 60 s	80.7	97.5	Sludge + UD, A = 45 μm, t = 60 s + 0.5 g ash	77.8	90.0

1	2	3	4	5	6
Sludge + UD, A = 45 μm, t = 90 s	80.1	96.8	Sludge + UD, A = 45 μm, t = 90 s + 0.5 g ash	76.8	90.5
Sludge + UD, A = 90 μm, t = 30 s	83.9	95.9	Sludge + UD, A = 90 μm, t = 30 s + 0.5 g ash	78.8	90.6
Sludge + UD, A = 90 μm, t = 60 s	81.8	97.1	Sludge + UD, A = 90 μm, t = 60 s + 0.5 g ash	78.1	89.2
Sludge + UD, A = 90 μm, t = 90 s	79.2	96.4	Sludge + UD, A = 90 μm, t = 90 s + 0.5 g ash	77.3	90.3
Sludge + 0.5 g cement	78.2	91.8	Sludge + 0.5 g gypsum	74.8	91.2
Sludge + UD, A = 45 μm, t = 30 s + 0.5 g cem.	85.5	91.1	Sludge + UD, A = 45 μm, t = 30 s + 0.5 g gyp.	80.6	91.2
Sludge + UD, A = 45 μm, t = 60 s + 0.5 g cem.	81.7	91.1	Sludge + UD, A = 45 μm, t = 60 s + 0.5 g gyp.	80.5	91.0
Sludge + UD, A = 45 μm, t = 90 s + 0.5 g cem.	82.8	91.5	Sludge + UD, A = 45 μm, t = 90 s + 0.5 g gyp.	78.0	90.0
Sludge + UD, A = 90 μm, t = 30 s + 0.5 g cem.	78.9	91.3	Sludge + UD, A = 90 μm, t = 30 s + 0.5 g gyp.	79.5	90.1
Sludge + UD, A = 90 μm, t = 60 s + 0.5 g cem.	75.0	91.6	Sludge + UD, A = 90 μm, t = 60 s + 0.5 g gyp.	76.8	90.5
Sludge + UD, A = 90 μm, t = 90 s + 0.5 g cem.	76.3	91.2	Sludge + UD, A = 90 μm, t = 90 s + 0.5 g gyp.	77.5	90.3

* Ultrasounds.

4. CONCLUSIONS

Based on the results of the present investigations it can be inferred that sewage sludge conditioning by the ultrasonic field and the application of selected components improves the effect of its dewatering. This conclusion is supported by low values of the final hydration obtained during centrifugation. The following conclusions can be drawn:

1. Higher rates of rotation applied in order to dewater sewage sludge subjected to conditioning by the selected methods decreased its final hydration.
2. The lowest final hydration during centrifugation was achieved in the case of combining sonication with the addition of selected components to sewage sludge.
3. The highest efficiency of dewatering was achieved for ash at the ultrasound wave amplitude of 90 μm and the exposure time of 90 s. The final hydration was 83.3% which corresponded to the change in sludge volume by 68% in comparison with non-treated sewage sludge.
4. Selected components added to sewage sludge reduced the efficiency of separation of solid phase from water. However, this did not affect significantly the favourable results of the final hydration of sewage sludge subjected to centrifugation.

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REFERENCES

[1] BIEŃ J.B., WOLNY L., WOLSKI P., *Działanie ultradźwięków i polielektrolitów w procesie odwirowania osadów ściekowych*, Inżynieria i Ochrona Środowiska, 2001, t. 4, nr 1, 41–50.

[2] BIEŃ J.B., WOLNY L., WOLSKI P., *Wpływ ultradźwięków na strukturę osadów ściekowych w procesie ich kondycjonowania*, Osady ściekowe – problem aktualny, XII konferencja naukowo-techniczna, Częstochowa–Ustroń, 2001.

[3] BIEŃ J., STĘPNIAK L., WOLNY L., *Ultradźwięki w dezynfekcji wody i preparowaniu osadów ściekowych przed ich odwadnianiem*, Wydawnictwo Politechniki Częstochowskiej, Częstochowa, 1995.

[4] DYMACZEWSKI Z., KEMPA E.S., SOZAŃSKI M.M., *Coagulation as a structure-forming separation process in water and wastewater treatment*, Wat. Sci. Tech., 1997, Vol. 34, No. 4, 25–32.

[5] FLORKIEWICZ A., KRAJEWSKI P., LESZCZYŃSKA M., SOZAŃSKI M.M., *Technologia usuwania i unieszkodliwiania osadów z uzdatniania wody*, Wydawnictwo Politechniki Poznańskiej, Poznań, 1999.

[6] KOWALCZYK M., WOLSKI P., *Problematyka wybranych mikrozanieczyszczeń w osadach ściekowych i pokoagulacyjnych*, materiały konferencji naukowo-technicznej *Mikrozanieczyszczenia w środowisku człowieka*, Konferencje, 44, 14–16 X, 2001, Ustroń, 157–164, Politechnika Częstochowska.

[7] OLSZANOWSKI A., SOZAŃSKI M.M., URBANIAK A., VOELKEL A., *Remediacja i bioremediacja zanieczyszczonych wód i gruntów oraz wykorzystanie modelowania i technik informatycznych w inżynierii środowiska*, Wydawnictwo Politechniki Poznańskiej, Poznań, 2001.

[8] SOZAŃSKI M.M., GROCHOLSKI K., KEMPA E.S., URBANIAK A., *Struktura osadów pochodzących z oczyszczania wody i ścieków*, materiały konferencji *Osady ściekowe, odpad czy surowiec?* Częstochowa, 26–28 czerwca 1997, 179–192.

[9] SZWABOWSKA E., *Projektowanie procesów odwadniania osadów ściekowych*, Wydawnictwo Politechniki Śląskiej, Gliwice, 1986.

[10] ZHAO Y.Q., *Enhancement of alum sludge dewatering capacity by using gypsum as skeleton builder*, Colloids and Surfaces, Physicochemical and Engineering Aspects, 2002, 211, 205–212.

[11] ZHAO Y.Q., BACHE D.H., *Conditioning of alum sludge with polymer and gypsum*, Colloids and Surfaces, Physicochemical and Engineering Aspects, 2001, 194, 213–220.