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STUDIES ON ULTRASONIC FIELD AND ELECTROCOAGULATION IN ULTRASONIC FIELD APPLIED TO THE SLUDGE TREATMENT

The paper presents a part of investigations concerning the influence of ultrasonic and combined ultrasonic and electric fields on the properties of sludge prior to its mechanical dewatering. The influence of sound application time within a range of 30–600 seconds on the changes in final water content after vacuum filtration and centrifugation was investigated. In parallel to dewatering the electrokinetic potential changes resulting from ultrasonic field application as a one of the parameters that characterize sludge susceptability to dewatering have been investigated. Research on the application of electrocoagulation in ultrasonic field was carried out for the voltages within 4–28 V at 15–300 s. The best effect, i.e. the decrease in final water content by 5.85%, has been obtained for the voltage of 16 V and time of 180 s.

1. INTRODUCTION

At present sludge is usually conditioned chemically prior to its dewatering in vacuum filters, centrifuges, filter or screen-belt presses. Both inorganics (iron chloride ($FeCl_3$), aluminum sulphate ($Al_2(SO_4)_3$)) and organics (polyelectrolytes based on polyacrylamides and polyamines) are applied as sludge conditioners. Polyelectrolytes are being widely used, particularly in water treatment sludge conditioning. Chemical pretreatment of sludges, though it is economical and quite effective, nevertheless it consumes large amounts of chemicals.

The laboratory studies on sludge treatment with the ultrasonic field yielded encouraging effects [2, 3, 7], which, however, may differ depending on the type of sludge or that of chemicals used in sludge dewatering. At the same time a number of phenomena associated with the ultrasonic field effect on sludge have not been cleared up as yet. Cavitation, activation and sensibilisation are known to occur in fluids under the impact of ultrasonic waves. A number of phenomena are also explained in literature by dispersion.

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Conditioning of sludge by ultrasonic waves changes its structure and properties to the extent resulting in the increase of its dewatering properties. Conditioning-induced changes in dispersion degree, hydrofobic properties and electrokinetic potential of colloidal and suspended particles as well as those occurring in viscosity and surface tension of the liquid lead to the reduction of forces binding water with solid particles. Due to the above changes free water, easy to remove during mechanic dewatering, is partially formed from the capillary and coloidally bound water. This results in better dewatering of municipal and industrial sludges [3, 4, 7]. It seems, however, that taking into account the present stage of the knowledge in this field neither any general conclusions can be formulated nor given the univocal explanation of the mechanism of the changes observed.

From the studies on the coagulation mechanism it is known that zeta potential of colloids is the essential parameter of the process [12].

A decrease in the zeta potential can be caused by the addition of an electrolyte or a polyelectrolyte, or by the other factors disturbing the stability of colloids, e.g. it can be due to the ultrasonic or electromagnetic fields.

According to a number of authors [1, 10, 13] electrical forces generated in the ultrasonic field can be one of the factors causing the changes in zeta potential and finally the ultrasonic coagulation. As a result of assymetry of the double electrical layer of colloidal particles (which is explained by the difference in the amplitudes of periodic oscillations of the particles of different masses) they behave as dipoles of instantaneous variable moments. Such distrubances increase the possibility of collision and attraction of particles resulting eventually in coagulation. Thus, the changes in zeta potential values of the sludges examined are considered to be the major parameter characterizing sludge susceptability to dewatering and allowing the effective control of the sludge conditioning by ultrasonic field and for those reasons it was also included in the reported study.

Zeta potential determinations were done by measuring electrophoretic mobility, employing the methods used to control the coagulation process in water treatment [8, 12]. Electrophoretic mobility was calculated from the formula:

$$U = \frac{nla}{V\tau}\left[\frac{\mathrm{m}^2}{\mathrm{V \cdot s}}\right],$$

where:

n — number of particles,

l — electrodes spacing [m $\times 10^{-2}$],

a — distance covered by the particle [m $\times 10^{-6}$],

V — voltage [V],

τ — total time of the particle transition [s].

Electrokinetic potential has been calculated from Smoluchowski's equation which gives the relationship between electrophoretic mobility and zeta potential [8]:

$$U = \frac{D\zeta}{4\pi\eta},$$

where:

U — electrophoretic mobility, $[m^2/V \cdot s]$

D — dielectric constant, $[N/V^2]$

ζ — electrokinetic potential, $[V \times 10^{-3}]$

η — viscosity of the medium. $[N \cdot s/m^2]$.

The interesting results, obtained from investigation of sound amplification, have encouraged the authors to simultaneous application of electrical and ultrasonic fields.

Electrocoagulation has found some application in surface water treatment for municipal purposes in U.S.A., Soviet Union, and Japan [5, 6, 14]. It can also be used in municipal and industrial wastewater treatment [9, 11]. The results of works on electrocoagulation in batch conditions and those of the industrial processes in flow-through conditions indicate that the effect of the process depends on the shape, dimension and spacing of electrodes, and on the geometrical and structural characteristics of the electrocoagulation unit. The process depends also on the voltage and current intensity as well as on a type of electrical field. The course of the process and sludge dewatering results are affected by duration of electrocoagulation cycle and the material of electrodes.

2. EXPERIMENTAL

In the first part of the investigation the inorganic sludge, composed mainly of grains and metal hydroxid gels, has been investigated at three temperatures: 283 K, 291 K, and 298 K. For sound amplification an ultrasonic disintegrator UD-11 (Polish made) has been used with the oscillation frequency of 20 kHz and amplitude of 0.32 m/s.

Sound-amplifed sludges have been dewatered by laboratory centrifuge WF-2 (spining time 5 min, 3000 revolutions/min) and vacuum filtration (pressure of 5.6×10^4 N/m^2). Electrokinetic potential of sludge particles has been also measured.

Electrophoretic mobility of the sludge single particles was determined using microscope (56 × magnification) and Riddick cell system with circular capillary section (diameter 5.1 mm, electrode spacing 10 cm) at electric current voltage of 300 V.

As the sewage sludge was characterized by a high concentration of dry mass and very high concentration of electrolytes in order to enable the observation, the sample dilution ratio with water 1:50 had to be applied. The results are given in figs. 1 and 2.

A digested sludge with water content of 95.3%, taken from the closed digester from the wastewater treatment plant, has been used in the second study.

This sludge has been conditioned applying: electrical field in the first run and electrical field combined with ultrasonic field in the second run. Research was carried out at 4, 9, 16, 23, and 28 d.c. voltage during 15, 30, 45, 60, 120, 180, and 300 s in batch conditions with the electrode spacing of 30 mm.

The ultrasonic disintegrator produced a 20 kHz ultrasonic field which was checked as optimal in the preceeding research [2, 3, 4, 7]. The lab sludge conditioning unit is presented in fig. 3. As a control of the sludge dewatering degree the final water content in the centrifuged (5 min, 3000 rev./min) or filtered sludge has been established.

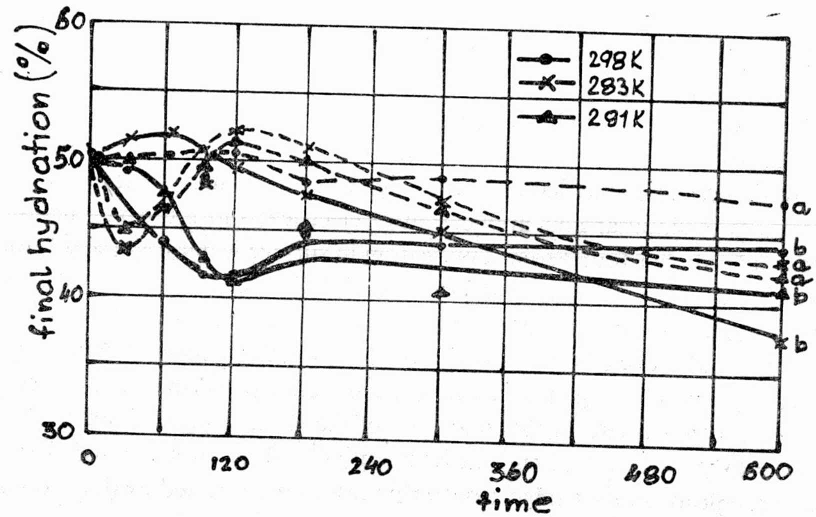

Fig. 1. Final water content versus time of sound application and temperature

a — after centrifugation, *b* — after vacuum filtration

Rys. 1. Finalna zawartość wody w zależności od stosowania dźwięku i temperatury

a — po odwirowaniu, *b* — po filtracji próżniowej

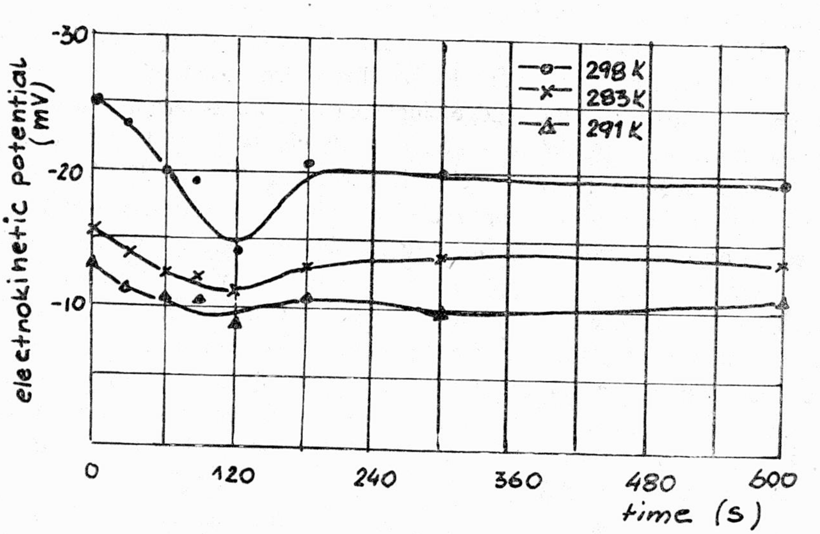

Fig. 2. Electrokinetic potential versus time of sound application and temperature

Rys. 2. Potencjał elektrokinetyczny w zależności od stosowania dźwięku i temperatury

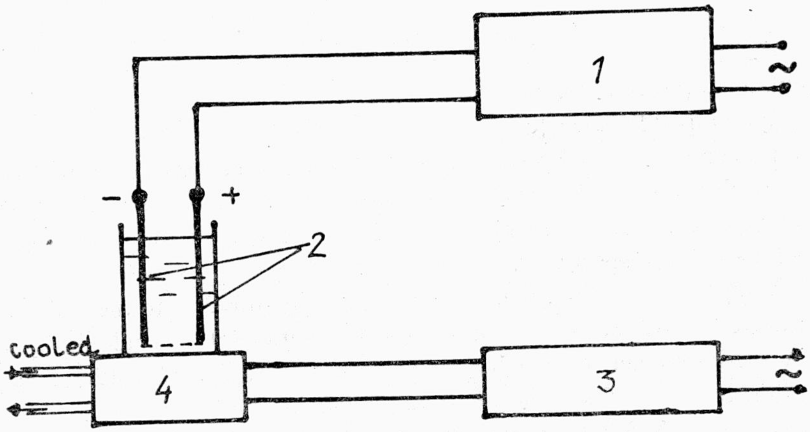

Fig. 3. Laboratory set

1 — d.c. power supply, *2* — steel electrodes, *3* — ultrasonic disintegrator, *4* — ultrasonic water-cooled head

Rys. 3. Zestaw laboratoryjny

1 — zasilanie prądem stałym, *2* — elektrody stalowe, *3* — dezintegrator ultradźwiękowy, *4* — głowica ultradźwiękowa chłodzona wodą

3. RESULTS AND DISCUSSION

Figure 1 shows the results of raw and conditioned sludge dewatering by centrifugation (curves *a*) and vacuum filtration (curves *b*) in three temperatures, while changes in the value of electrokinetic potential versus the time of sound amplification are presented in fig. 2. The correlation between the changes of final water content and changes of zeta potential has been stated; as the decrease in final water content was accompanied by that of zeta potential, their extremal values being strictly correlated with sound application time of 120 seconds both in case of centrifugation and vacuum filtration. From the results presented graphically in fig. 2 the following mathematical relationship between the time of sound amplification, temperature of measurement and zeta potential was derived:

$$\zeta = a(t)\tau + b(t)|\tau-120| + c(t)|\tau-180| + d(t),$$

where:

ζ — electrokinetic potential $[\mathrm{V} \times 10^{-3}]$,

$$a(t) = \frac{1}{67200}(684.5t+691.5|t-18|-10977)\left[\frac{\mathrm{V}\times 10^{-3}}{\mathrm{s}}\right],$$

$$b(t) = \frac{1}{67200}(-316.5t-267.5|t-18|-3121)\left[\frac{\mathrm{V}\times 10^{-3}}{\mathrm{s}}\right],$$

$$c(t) = \frac{1}{67200}(368t+424|t-18|-7856)\left[\frac{\mathrm{V}\times 10^{-3}}{\mathrm{s}}\right],$$

$$d(t) = \frac{1}{67200} (901t + 691|t-18| - 30442) \ [V \times 10^{-3}],$$

τ — sound amplification time [s],
t — temperature (T—273) [deg].

Final water content of the digested and centrifuged sludge, being not previously subject to electrical or ultrasonic field, was equal to 69.00%, while in case of the sludge pretreated by electrical field of 4 V for 15 s and 9 V for 30 s it reached its minimal values equal to 68.63% and 68.47%, respectively.

For the voltage of 16 V water content kept increasing for 30 s to the value of 70.36% and then it decreased reaching its minimum (68.41%) after 180 s. Analogically, at the voltage of 23 V the parameter has reached its maximum (70.35%) after 45 s, then it rapidly dropped within the next 15 s to its minimum equal to 68.44%.

For the voltage of 28 V a slight deviation (of about 1%) has been observed in the final water content, its lowest value (68.95%) being obtained after 45 s. These predetermined optimal times of sludge exposure to electrical field (being different for particular voltages) were applied when a combined effect of electric and ultrasonic fields was studied.

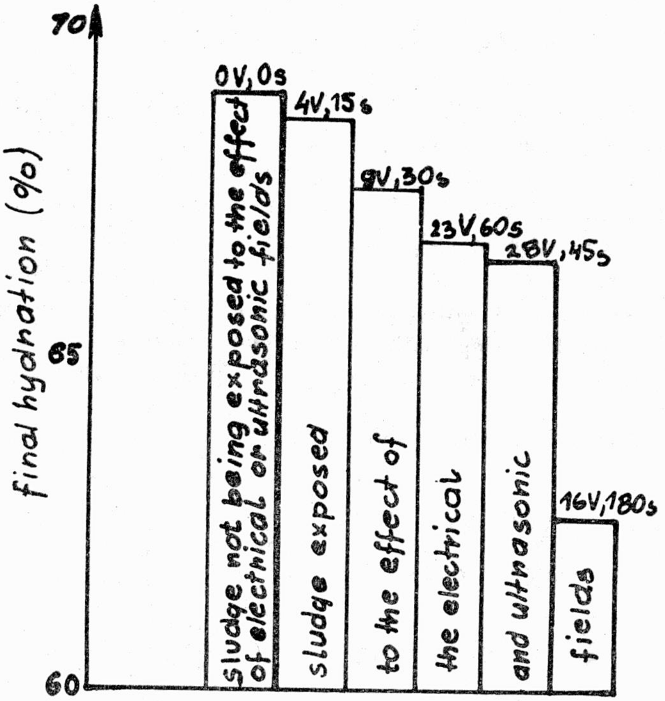

Fig. 4. Change in the final water content of sludge due to the exposure to ultrasonic and electrical fields
Rys. 4. Zmiana końcowej zawartości wody w osadzie spowodowana zastosowaniem pola ultradźwiękowego i elektrycznego

Simultaneous application of ultrasonic and electrical fields has improved the sludge dewatering effect except for the voltage of 4 V at which it remained the same as without sound amplification (fig. 4). Sound application resulted in the final water content in the sludge 67.56%, whereas at the voltage of 23 V and time of 60 s it was equal to 66.89%, at the voltage of 28 V and time of 45 s being equalled to 66.6%. The best dewatering effect was obtained for 16 volts and 180 s (final water content 62.56%).

4. CONCLUSIONS

The results obtained during the research have confirmed that method of the application of ultrasonic and electrical fields in the sludge treatment was correct. Thus, a combined use of ultrasonic and electrical fields improved the sludge dewatering: by 0.91% at the voltage of 9 V and the time of 30 s, by 1.55% at the voltage equal to 23 V and time of 60 s, and by 2.34% at 28 V and 45 s. The best effect, i.e. the decrease in the water content by 5.85%, has been obtained for the voltage of 16 V at the time of 180 s.

A combined application of both ultrasonic and electrical fields for treatment of sludges prior to their mechanical dewatering has not been so far described in the literature. Therefore the results obtained may be controversial at times. However, the method given allows us to assume that further research is needed.

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BADANIA POLA ULTRADŹWIĘKOWEGO I ELEKTROKOAGULACJI W POLU ULTRADŹWIĘKOWYM STOSOWANYCH DO KONDYCJONOWANIA OSADÓW ŚCIEKOWYCH

Przedstawiono fragment badań nad wpływem pola ultradźwiękowego, a także łącznego działania pola ultradźwiękowego i elektrycznego, na zmiany właściwości osadów ściekowych w aspekcie przygotowania tych osadów do odwadniania na urządzeniach mechanicznych. Zbadano wpływ czasu stosowania ultradźwięków (30–600 s) na zmiany w końcowym uwodnieniu osadu, po filtracji i wirowaniu. Zbadano też zmiany potencjału elektrokinetycznego cząstek jako jednego z parametrów charakteryzujących podatność osadu na odwadnianie. Badania dotyczące zastosowania elektrokoagulacji w polu ultradźwiękowym prowadzono dla napięć prądu stałego w zakresie 4–28 V w czasie 15–300 s. Najlepszy efekt (zmniejszenie uwodnienia końcowego o 5,85%) uzyskano dla 16 V w czasie 180 s.

EINFLUSS DES ULTRASCHALLFELDES UND DER ELEKTROKOAGULATION IM ULTRASCHALLFELD BEI DER KONDITIONIERUNG VON ABWASSERSCHLÄMME

Wiedergegeben wird ein Versuchsausschnitt über den Einfluß des Ultraschallfeldes sowie einer gemeinsamen Wirkung des Ultraschall- und des elektrischen Feldes auf die Eigenschaften von Abwasserschlämmen während ihrer Konditionierung bevor sie einer mechanischen Entwässerung unterzogen werden. Untersucht wurde der Einfluß des Zeitfaktors des Ultraschalls (30–600 s) auf den Wassergehalt des Schlammes nach der Entwässerung. Untersucht wurde auch das elektrokinetische Potential der Schlammpartikeln. Der Einfluß der Elektrokoagulation im Ultraschallfeld wurde bei Gleichstromspannungen von 4–28 V und Zeiten von 15 bis 300 s untersucht. Beste Resultate (d.h. eine Abnahme des Wassergehaltes um 5,85%) erzielte man bei 16 V und 180 s.

ИССЛЕДОВАНИЯ УЛЬТРАЗВУКОВОГО ПОЛЯ И ЭЛЕКТРОКОАГУЛЯЦИИ В УЛЬТРАЗВУКОВОМ ПОЛЕ, ИСПОЛЬЗУЕМЫХ ДЛЯ КОНДИЦИОНИРОВАНИЯ ОСАДКОВ СТОЧНЫХ ВОД

Представлен фрагмент исследований по влиянию ультразвукового поля, а также совместного действия ультразвукового и электрического полей на изменения свойств осадков сточных вод в аспекте подготовки этих осадков к обезвоживанию на механических установках. Исследовано влияние продолжительности применения ультразвуков (30–600 с) на изменения в конечном обезвоживании осадка после фильтрации и центрифугирования. Были исследованы также изменения электрокинетического потенциала частиц как одного из параметров, характеризующих податливость осадка на обезвоживание. Исследования, касающиеся применения коагуляции в ультразвуковом поле, проводились для напряжений постоянного тока в пределах 4–25 В при продолжительности 15–300 с. Наилучший эффект (снижение конечной гидратации на 5,85%) был достигнут для 16 В при продолжительности 180 с.