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IMPACT OF ULTRASONIC FIELD STRENGTH ON THE STRUCTURAL CHANGES OF DISINTEGRATED EXCESS SLUDGE

Mariusz BARAŃSKI, Iwona ZAWIEJA, Lidia WOLNY
Czestochowa University of Technology
Faculty of Engineering and Environmental Protection
Institute of Environmental Engineering
Brzeźnicka st. 60A, 42 – 200 Czestochowa, Poland

Exposure of sludge to the ultrasonic field as a disintegrating factor before the mesophilic anaerobic stabilisation directly affects the increase in the susceptibility of sludge on the biochemical process of decomposition in the anaerobic conditions. Thanks to the use of sewage sludge pretreatment, an increase of the disintegration degree of sludge undergoing physical modifications is reached, as well as the intensification of biogas production. The aim of the study was to record changes in the structure of excess sludge tested, as well as the determination of disintegration degree [%] versus the strength of ultrasound wave [W/cm^2]. An ultrasonic disintegrator VCX – 1500 (Sonics Company) was used in the investigation. The test substrate was excess sludge from the Central Wastewater Treatment Plant P.S.W. "WARTA" in Czestochowa. Two cycles of tests were conducted, which implement the following amplitude A = 7.85 μm and 39.25 μm and the time of sonification ts = 30 ÷ 360s. The most beneficial effect of ultrasound treatment on the excess sludge was noted for the amplitude A=39.25 μm and the sonication time 360s, which resulted in 83.25% degree of disintegration of excess sludge. For these parameters, the strenght of ultrasonic wave was 4.8 W/cm^2. In addition, a large dispersion of sludge particles prepared with ultrasonic field and enlargement of the liquid phase in relation to unconditioned sludge were observed. The noted changes of structure correlate with the obtained degree of disintegration of the excess sludge.

Keywords: excess sludge, sludge structure, physical conditioning, chemical oxygen demand (COD), anaerobic stabilisation

Corresponding author. E-mail: pwolski@is.pcz.czest.pl

1. INTRODUCTION

An important research issue, undertaken by many researchers in view of the increasing environmental pollution, is to modernize the existing wastewater treatment technologies and creating new, more effective solutions. Several studies are carried out which aim at increasing the susceptibility of excess sludge in the process of biochemical degradation under anaerobic conditions. One seeks how to improve the process of anaerobic stabilization, digester volume reduction and utilization of increasing quantities of sludge [1,2]. Physical methods of sludge conditioning, including the ultrasonic field, are an important disintegrating factor, used before the anaerobic stabilization process. The use of active acting ultrasonic field causes fragmentation and destruction of excess sludge microbial cells. Ultra-sonic pretreatment effectively intensifies the biochemical processes taking place during hydrolysis, as well as during the acidogenic phase of anaerobic stabilization [3]. The result of the process of disintegration is the greater availability of organic matter to carry out the anaerobic stabilization, which in turn means a reduction of hydrolytic phase of fermentation and acceleration and intensification of the processes taking place in successive stages, such as increase of VFA output [4, 5]. In the case of anaerobic stabilisation process of sludge, the important energetic issue is intensification of biogas generation. The applied sewage sludge physical pretreatment influenced the increase of disintegration degree, as well as the intensification of biogas production. The ultrasound used to sludge disintegration had the requency in the range from 1910 to 1950 kHz and high strenght over 1 W/cm^2 is used [6].

2. EXPERIMENTAL PART

2.1. Test substrate

Test substrate was excess sludge, coming from the Central Wastewater Treatment Plant PSW "WARTA" in Czestochowa. The excess sludge was taken from the pressure pipeline transporting sludge to a mechanical thickener. Table 1 shows the general characteristics of sludge used in the study.

Table 1. General characteristics of sewage sludge used in the study

Parameter / The sort of sludge	Hydration	Dry mass	Dry org. mass	Dry min. mass	Volatile fatty acids (VFA)	Chemical oxygen demand (COD)
	%	g/dm^3	g/dm^3	g/dm^3	$mgCH_3COOH/dm^3$	mgO_2/dm^3
Excess sludge	98,92	7,22	5,12	2,02	55	105

2.2. Materials and methods

The aim of this study was to illustrate changes in the structure of excess sludge, as well as to determine the degree of disintegration [%] in terms of changes of ultrasound strenght [W/cm^2]. As a measure of physical-chemical and biological transformations occurring in sludge from the application of ultrasonic field, changes in the chemical oxygen demand (COD) in sludge water was adopted. Marking of COD was done by using the tests to the spectrophotometer HACH 2100N IS according to ISO 7027. Microscopic preparations were made to observe changes in the structure of sludge. To observe the structure of the sludge the microscope OLIMPUS BX 41 with instrumentation for takeing pictures was used. Observations were carried out using a 10-fold magnification. In order to determine the degree of disintegration, according to the formula (1), the sludge was conditioned with 1 M NaOH during 10 min. at 90 ° C, while maintaining the ratio of volume of sludge and the reconstituted solution (1:1). According to this methodology for the alkaline conditioned surplus sludge, the value of chemical oxygen demand of 2350 mgO_2/dm^3 was obtained. The value of disintegration degree was determined using the formula [7]:

$$D_{COD} = (COD_1\text{-}COD_2) / (COD_3\text{-}COD_2) \bullet 100 \quad (1)$$

where: D_{COD} – disintegration degree (%);
COD_1 – COD value for sludge conditioned UD (mgO_2/dm^3);
COD_2 – COD value for the unconditioned sludge (mgO_2/dm^3);
COD_3 – COD value for a chemically conditioned sludge- 1 M NaOH in the ratio 1:1, temperature 90 ° C for 10 minutes (mgO_2/dm^3).

The strenght of ultrasonic wave was calculated by the following formula [7]:

$$IA = EA / S \bullet t_s \quad (2)$$

where: IA – ultrasonic strenght (W/cm^2);
EA – the amount of energy supplied (J);

S – cross section of ultrasonicated sample (cm^2);

t_s – time of sample ultrasonication (s).

Conditioning was performed using an ultrasonic disintegrator with automatic tuning (type VCX - 1500 of the American company Sonics). The maximum power output of this generator is 1500W, the vibration frequency of ultrasound field 20kHz. Disintegrator sonotrode was immersed in a vessel of the test sludge at a depth of about 4 cm from the bottom of the dish. The volume of the conditioned sample was 0.5 dm^3. Evaluation of the impact of ultrasonic field on the excess sludge was conducted in two research cycles, using the following amplitudes (39.25 μm = 100%): A = 7.85 μm and 39.25 μm. Sonification time was used between: $t_s = 30 \div 360$s.

3. RESULTS

Changes of COD values in supernatant of sludge after ultrasonic pretreatment with definite vibration amplitude and exposure time (Table 2) were determined in the first order. The highest values of COD, for both studied amplitudes was obtained for the time 360s. For the amplitude 39.25 μm and sonification time 360s, 1970 mg O_2/dm^3 was recorded, the value of more than 3-fold higher with respect to the amplitude of 7.85 μm for which the obtained COD parameter amounts to the value of 602 mg O_2/dm^3.

Table 2. COD changes marked in the supernatant of excess sludge after ultrasonic field conditioning

Vibration amplitude / Sonification time, s	A=7,85μm	A=39,25μm
	ChZT, mg O_2/dm^3	
Sample 0	105	105
30	95	250
60	133	470
90	190	590
120	280	662
150	321	850
180	343	1056
210	368	1135
240	390	1260
270	480	1390
300	521	1540
330	560	1724
360	602	1970

For individual samples of sludge and the applied amplitudes, increasing values of energy have been noted, depending on the exposure time (Table 3). The greatest value of the inputting energy, 110084 J, was obtained for vibration amplitude of 39.25 μm and time of sonification 360 s, for vibration amplitude of 7.85 μm and time 360s it is 37 161 J.

Table 3. Changes in the amount of energy supplied to the disintegrator sonotrode during sludge conditioning process with ultrasounds

Vibration amplitude / Sonification time, s	A=7,85μm	A=39,25μm
	Energy, J	
Sample 0	-	-
30	2973	8672
60	5946	17301
90	8986	25607
120	11923	34658
150	14910	43304
180	17918	51778
210	21320	60688
240	23974	70650
270	27528	80498
300	30596	90623
330	33749	100758

In the case of the test amplitude 7.85 μm and 39.25 μm the highest value of the disintegration degree equal respectively to 22.99% and 83.25% were obtained for the time of sonification 360s, see Table 4.

In the case of amplitude of 7.85 μm the strenght of ultrasonic waves oscillated within 1.56÷1.62 W/cm^2, while for the higher amplitude it was in the range of 4.48 ÷ 4.8 W/cm^2. Changes of the values of the disintegration degree and the strenght of the ultrasound wave, for the researched amplitudes depending on the values of sonification time are shown in Figures 1 and 2.

Table 4. Values of the disintegration degree for a specified amplitude and exposure time

Vibration amplitude, μm	Sonification time, s	Disintegration degree, %
Sample 0	-	-
7,85	30	0,66079
	60	2,3348
	90	4,84581
	120	8,81057
	150	10,6167
	180	11,5859
	210	12,6872
	240	13,6564
	270	17,6211
	300	19,4273
	330	21,1454
	360	22,9956
39,25	30	7,48899
	60	17,1806
	90	22,467
	120	25,6388
	150	33,9207
	180	42,9956
	210	46,4758
	240	51,9824
	270	57,7093
	300	64,3172
	330	72,4229
	360	83,2599

During microscopic observation of unprepared excess sludge structure it was observed visible spaces in the liquid phase and the coarse-grained clusters of solid particles (Figure 3). The structure of the treated sludge by ultrasonic field was characterized by a large crusher solid phase.

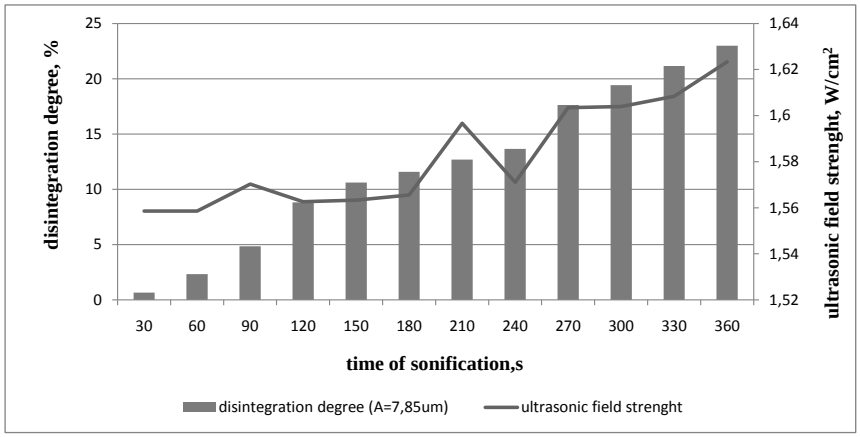

Fig. 1. Disintegration degree values and the strenght of ultrasonic wave for the amplitude of 7.85 μm, depending on the sonification time

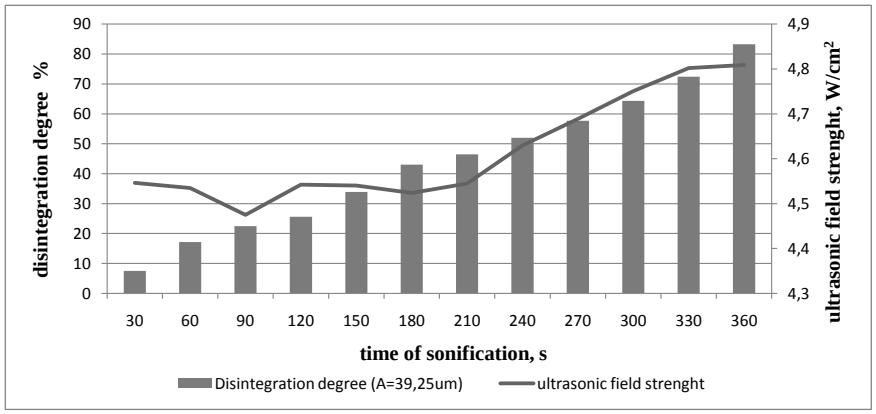

Fig. 2. Disintegration degree values and the strenght of ultrasonic wave for the amplitude of 39.25 μm, depending on the sonification time

Figure 4 and 5 shows the changes in the structure of sludge observed in the case of the vibration amplitude of 7.85 μm and 39.25 μm and the best possible exposure time 360s. The studies confirmed that with increasing amplitude and duration of conditioning liquefaction of sludge structure also increased.

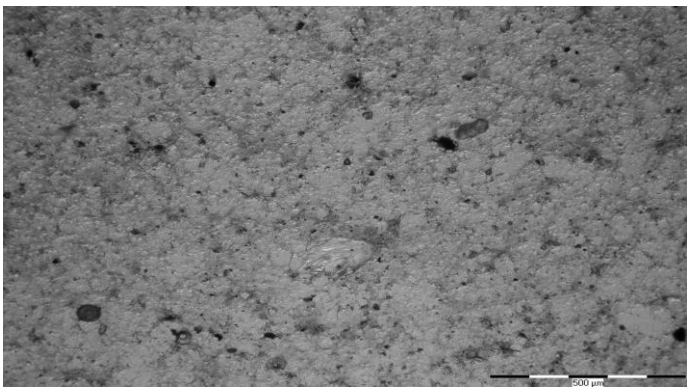

Fig. 3. Structure of unprepared excess sludge

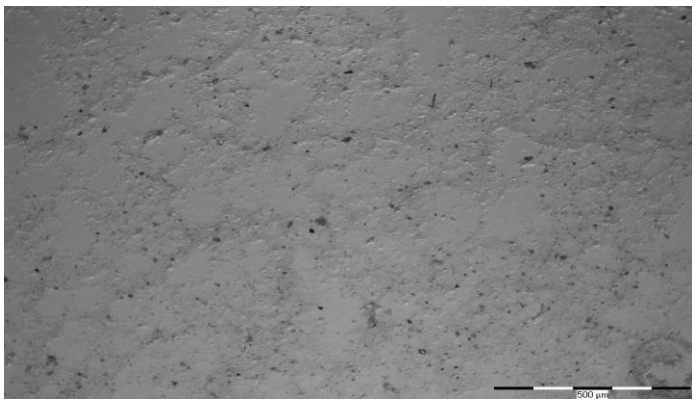

Fig. 4. Structure of ultrasonic pretreatment excess sludge for the amplitude A = 7.85 μm and exposure time 360s

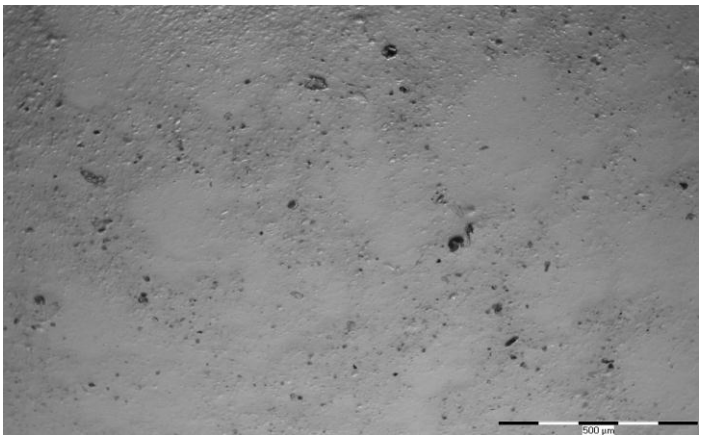

Fig. 5. Structure of ultrasonic pretreatment excess sludge for the amplitude A = 39.25 μm and exposure time 360s

4. CONCLUSIONS

Based on literature review and obtained results of studies on the effectiveness of ultrasonic field as a disintegration factor, the following conclusions were formulated:

– With the increase of amplitude get a much greater degree of disintegration excess sludge. For the amplitude of 39.25 μm the degree of disintegration was 83.25% and was approximately 4-fold higher in relation to the amplitude of 7.85 μm, for which reported the value of 22.99%.

– In relation to structure of raw sewage sludge for sludge ultrasonicated with an amplitude of 39.25 μm a significant dispersion of sediment particles and the simultaneous expansion of the liquid phase was observed.

– Changes in structure correlate with the obtained of excess sludge disintegration degree, as well as the value of the strenght of the ultrasound wave. For the amplitude of 39.25 μm and sonification time 360s the value of the strenght of the ultrasound wave was 4.8 W/cm^2. This value was accordingly three times higher in relation to the value of ultrasonic field strenght for amplitude A=7.85 μm and 360s of the sonification time.

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WPŁYW NATĘŻENIA POLA UD NA ZMIANY STRUKTURY DEZINTEGROWANYCH OSADÓW NADMIERNYCH

S t r e s z c z e n i e

Poddanie osadów działaniu pola ultradźwiękowego, jako czynnika dezitegrującego przed procesem mezofilowej stabilizacji beztlenowej wpływa bezpośrednio na zwiększenie podatności osadów na proces biochemicznego rozkładu w warunkach beztlenowych warunkując szybkość przebiegu fazy hydrolitycznej fermentacji metanowej. Dzięki zastosowaniu prekondycjonowania osadów ściekowych uzyskuje się wzrost stopnia przefermentowania osadów poddanych fizycznej modyfikacji, jak również intensyfikację produkcji biogazu. Celem prowadzonych badań przy użyciu dezintegratora ultradźwiękowego o mocy 1500W z automatycznym strojeniem typu VCX–1500 amerykańskiej firmy SONICS było zobrazowanie zmian zachodzących w strukturze osadów nadmiernych, jak również określenie wartości stopnia dezintegracji [%] od natężenia fali ultradźwiękowej [W/cm^2]. Substratem badań był nadmierny osad czynny pochodzący z Centralnej Oczyszczalni Ścieków P.S.W. „WARTA" w Częstochowie. Przeprowadzono dwa cykle badawcze, w których zastosowano następujące amplitudy drgań A = 7,85 μm i 39,25 μm oraz czas nadźwiękawiania t_n = 30 ÷ 360s. Najkorzystniejszy wpływ działania czynnego pola ultradźwiękowego na osady ściekowe odnotowano dla amplitudy A≈39,25 μm oraz czasu sonifikacji 360s, dla których uzyskano 83,25% stopień dezintegracji osadów nadmiernych. Natężenie fali UD dla omawianych parametrów pola ultradźwiękowego wynosiło 4,8 W/cm^2. Ponadto zaobserwowano znaczną dyspersję cząstek osadów preparowanych polem UD oraz powiększenie fazy ciekłej w odniesieniu do osadów niekondycjonowanych. Zmiany struktury korelowały z uzyskanym stopniem dezintegracji osadów nadmiernych.