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THE INFLUENCE OF ULTRASONIC FIELD ON CHEMICAL AND MICROBIOLOGICAL PARAMETERS OF STABILIZED EXCESSIVE SLUDGE

ABSTRACT *Anaerobic stabilization is one of the processes applied in modification of sewage sludge. That process is based on biochemical decomposition of macromolecular compounds in participation of suitable microbes. Usage of conditioning technology for sewage sludge before anaerobic stabilization leads to time reduction of that process. The investigations were done on excessive sludge coming from Central Wastewater Treatment Plant "Warta" S.A. in Częstochowa. Due to fact, that excessive sludge has structure consists of agglomeration of microbes cell it is unsusceptible for anaerobic stabilization. Active ultrasonic field application causes decomposition of microbes cells membranes and release of organic compounds from their interiors. This process increases the effectiveness of anaerobic stabilization.*

Process of anaerobic stabilization was carried out for 28 days in temperature of 37°C. First sample of excessive sludge was stabilized without conditioning, second sample was stabilized after conditioning in specified parameters of active ultrasonic field.

During anaerobic stabilization the following chemical analysis were done: dry matter, mineral dry matter, organic dry matter, volatile fatty acids (VFA), pH, alkalinity, acidity, Kjeldahl general nitrogen, ammonium nitrogen, chemical oxygen demand (COD), general phosphorus. Additionally, microbiological tests of microbes of Escherichia coli, psychrophiles and mezophiles microorganisms were done.

Keywords: *excessive sludge, anaerobic stabilization, ultrasonic field, biogas, microorganisms.*

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1. INTRODUCTION

Anaerobic stabilization is one of the processes applied in modification of sewage sludge. That process is based on biochemical decomposition of macromolecular compounds in participation of suitable microbes. Products of mentioned reaction are sewage sludge containing reduced contents of organic compounds and biogas as valuable energetic material [1, 2].

Excessive activated sludge that has characteristic flocculation structure of agglomerated microorganisms cells is unsusceptible on biodegradation process. Usage of sludge disintegration technique causes decomposition of microbes cells releases organic compounds from their interiors. Released organic compounds and enzymes are valuable substrates for anaerobic microorganisms taking part in anaerobic stabilization process.

The criterion of disintegration efficiency can be, among others, the increase in the content of organic substance in supernatant, which is measured by means of chemical oxygen demand (COD) concentration.

Disintegration of sewage sludge has also influence on chemical structure of released compounds causing breaking of strong chemical bonds obstructing biodegradation.

Usage of active ultrasonic field is one of sewage sludge disintegration methods before anaerobic stabilization process. It has influence on reduction the time of anaerobic stabilization process. The ultrasonic field was used to obtain the volume of sludge decrease and high biogas generation [3, 4].

2. METHODOLOGY

The substrate used for the investigations was activated sludge from the Warta Sewage Treatment Plant in Częstochowa, Poland. Anaerobic stabilization was carried out for 28 days using the arrangement which was comprised of fermentation chamber with the volume of 20 l with water jacket, heating system, cylinder for measurements of biogas which is released during the process and the overflow vessel (Fig. 1).

Furthermore, the fermentation chamber features temperature sensor, probe for measurement of pH and the stirrer which allowed for stable distribution of the contents of fermentation mixture. The system operated at the constant

Fig. 1. The system of anaerobic stabilization

temperature of 37°C ± 0.1°C [5]. The presented system was used for measurements of volume and for determination of the chemical composition of the generated biogas.

The mixture which was subjected to the process of anaerobic stabilization was comprised in 95% of excess sludge and in 5% of fermented sludge, which was a form of the inoculum that ensured proper course of fermentation.

Anaerobic stabilization was additionally carried out in laboratory flasks with volume of 500 ml, equipped in fermentation pipes. The flasks were placed in a laboratory thermostat set at 37°C ± 0.1°C. In order to ensure proper course of the process, e.g. to avoid accumulation of the scum on the surface of the fermented mixture, the content of flasks was mixed manually twice a day.

The investigations were carried out in two stages. The first stage involved stabilization of non-conditioned sludge. During the second stage, the sludge was stabilized after conditioning with ultrasonic field with the amplitude of 16 µm and exposure time of 5 min. Disintegration was carried out by means of ultrasound disintegrator UD-20 manufactured by Techpan with vibration frequency of 22 kHz. The sludge stabilized in the laboratory flasks was subjected to chemical and microbiological analysis for 10 consecutive days of the process and on the last (28th) day of fermentation.

The determined chemical parameters included dry matter, mineral dry matter, organic dry matter, hydration, volatile fatty acids (VFA), chemical oxygen demand (COD), ammonia nitrogen, total nitrogen, total phosphorus, acidity, alkalinity, pH in the sludge and pH in supernatant [6, 7, 8, 9].

The sludge was analysed in terms of changeable count of mesophilic and psychrophilic microorganism, and pathogenic species, i.e. *Escherichia coli.* Before microbiological analysis, the water from above the sludge was diluted from 10^{-1} to 10^{-7}.

In order to determine mesophilic and psychrophilic microorganism amount in the studied sludge, the methods of surface inoculation on Petri dishes were used. *Escherichia coli* were determined by means of fermentation test-tube method using liquid Eijkman broth; the doubtful sample was inoculated into solid

Endo agar plate. 1 μm of suitably diluted sludge was dosed respectively on the prepared Petri dishes and into the test-tubes with Eijkman broth. The samples were stored under conditions suitable for the examined microorganisms. After the growing period, the grown colonies of bacteria were evaluated and given as calculated per units which create colonies in 1 cm^3 [10].

3. RESULTS

Chemical determinations carried out during stabilization of non-conditioned sewage sludge are compared in Table 1.

Table 2 contains the results of chemical analyses of stabilization of the sludge conditioned with ultrasonic field.

Based on the obtained analysis, the authors compared the course of stabilization of the non-conditioned sludge and the sludge conditioned with ultrasonic field.

During stabilization, values of pH in both processes varied from 6.8 to 7.4, which is a suitable level for proper anaerobic stabilization. Acidity increased with the degree of fermentation of the sludge.

An essential indicator which determines the number of easily-decomposed organic substances in biostabilization processes is COD. The level of COD in both processes increased to a particular boundary value. The highest COD level for non-conditioned sludge was observed on the third day of the process, whereas this value for the conditioned sludge was obtained on the fourth day of the process. Before stabilization of the non-conditioned sludge, COD level was 245 mg O_2/dm^3 and increased to the value of 1155 mg O_2/dm^3. Before the process of stabilization, the sludge conditioned with ultrasound field showed higher COD level of 794 mg O_2/dm^3 and reached the highest level of 1532 mg O_2/dm^3, observed on the fourth day of the process. Furthermore, high values of COD were observed until the sixth day of stabilization, followed by a rapid decline.

The proper course of stabilization processes was also affected by the value of VFA concentration in the sludge. VFA levels rose in both processes until the second day of stabilization. During fermentation of non-conditioned sludge, a three-time increase in VFA level was observed, whereas in the sludge conditioned with ultrasonic field, a five-time increase in VFA level compared to the initial value was found [11, 12].

TABLE 1
Chemical indicators and parameters of non-conditioned sewage sludge before and during anaerobic stabilization process

			Chemical indicators and parameters of sewage sludge											
		Hydration, %	Dry matter, g/dm^3	Mineral dry matter, g/dm^3	Organic dry matter, g/dm^3	Acidity, mval/dm^3	Alkalinity, mval/dm^3	COD, mg O2/dm^3	VFAs, mgCH3COOH/dm^3	Kjeldahl's nitrogen, mg N/dm^3	Ammonium nitrogen, mg N-NH^{+4}/dm^3	Phosphorus, mg P/dm^3	Sludge pH	Sludge supernatant pH
Excessive sludge		99,28	7,15	5,09	2,06	2,8	4,4	146	68,6	22,4	11,2	0,34	7,02	6,47
Fermented sludge		98,39	16,06	9,87	6,19	8	56	1393	951,4	248,2	261,5	5,87	7,13	7,31
Mixed sludge		99,18	8,23	5,94	2,29	3,0	10	245	257,1	33,6	13,16	0,39	7,05	7,16
Anaerobic stabilization time, day	**1**	99,21	7,93	5,55	2,38	3,2	13,6	838	462,9	123,2	133,8	2,05	6,85	7,08
	2	99,35	6,46	4,53	1,93	3,2	18,2	860	634,3	168	148	2,39	6,83	7,06
	3	99,25	7,44	5,03	2,41	3,4	20,8	1155	522,9	175	154	2,61	6,83	7,05
	4	99,36	6,44	4,15	2,29	3,6	22,8	791	548,6	190,4	179,2	5,65	6,85	7,10
	5	99,36	6,43	4,12	2,31	4,8	24,4	579	342,9	190,4	204,4	5,7	6,94	7,25
	6	99,26	7,36	4,84	2,52	4,4	26	683	231,4	210	201,6	6,85	6,90	7,26
	7	99,25	7,54	4,69	2,85	3,8	26,8	507	205,7	182	207,2	7,33	7,02	7,19
	8	99,36	6,36	3,9	2,46	3,6	27,6	397	188,6	196	201,6	7,82	6,98	7,14
	9	99,34	6,58	4,27	2,31	2,8	28	567	325,7	176,4	201,6	7,94	7,23	7,39
	10	99,32	6,79	4,52	2,27	3,2	28,4	826	300	224	212,8	8,64	7,02	7,32
	28	99,41	6,35	4,26	2,09	5,8	34,2	804	317	364	280	14,34	6,97	7,09

TABLE 2

Chemical indicators and parameters of conditioned sewage sludge before and during anaerobic stabilization process

			Chemical indicators and parameters of sewage sludge											
		Hydration, %	Dry matter, g/dm^3	Mineral dry matter, g/dm^3	Organic dry matter, g/dm^3	Acidity, mval/dm^3	Alkalinity, mval/dm^3	COD, mg O2/dm^3	VFAs, mgCH3COOH/ dm^3	Kjeldahl's nitrogen, mg N/dm^3	Ammonium nitrogen, mg N-NH^{+4}/dm^3	Phosphorus, mg P/dm^3	Sludge pH	Sludge supernatant pH
Excessive sludge		99,03	9,67	6,44	3,23	1,2	5,0	226	60	22,4	28	0,163	6,74	7,19
Fermented sludge		97,94	20,61	12,27	8,34	7,4	65,2	1212	968,6	638,4	739,2	5,48	7,34	8,08
Conditioned sludge		99,03	9,73	6,56	3,17	1,0	5,4	669	120	24,5	28	0,72	6,87	7,28
Mixed sludge		98,94	10,6	6,95	3,65	2,0	11,2	794	205,7	123,2	112	1,06	7,15	7,58
Anaerobic stabilization time, day	**1**	99,06	9,37	5,97	3,4	3,0	17,2	1445	702,9	196	168	1,17	6,93	7,16
	2	99,09	9,14	5,81	3,33	3,48	20,8	1471	1054	218,4	224	1,17	6,90	7,02
	3	99,05	9,48	6,08	3,4	4,88	22,0	1485	891,4	240,8	252	1,22	6,96	7,09
	4	99,10	9,04	5,51	3,53	5,0	25,0	1532	994	271,6	263,2	1,27	7,00	7,04
	5	99,05	9,45	5,74	3,71	4,68	25,6	1370	960	271,6	280	1,27	6,98	7,08
	6	98.99	10,07	6,09	3,98	4,8	28,0	1160	754,3	280	280	1,32	7,17	7,24
	7	99,03	9,69	5,99	3,7	4,0	30,0	782	445,7	282,8	313,6	1,32	7,19	7,23
	8	99,05	9,44	5,71	3,73	3,2	30,2	687	308,6	299,6	319,2	1,35	7,48	7,65
	9	99,08	9,22	5,72	3,5	3,6	30,8	748	240	308	324,8	1,4	7,20	7,31
	10	99,10	9,00	5,58	3,42	4,4	31,6	757	188,6	313,6	324,8	1,51	7,29	7,34
	28	99,12	8,79	5,39	3,4	4,0	38	289	218,6	403,2	425,6	4,78	7,24	7,34

On the consecutive days of the process of stabilization, the increasing values of nitrogen and total phosphorus were also observed. These changes were caused by the decomposition of high-molecular organic compounds to more basic forms. More intensive growth of nitric compounds was observed during stabilization of the conditioned sludge compared to non-conditioned sludge. During fermentation, nitric compounds were partially transformed into ammonia form, which was confirmed by the results of the investigations.

The amount of biogas generated during 28-day stabilization of non-conditioned sludge and the sludge conditioned with ultrasound field was compared in Table 3.

Daily production of biogas of the non-conditioned sludge and the sludge conditioned with ultrasonic field is presented in Figure 2.

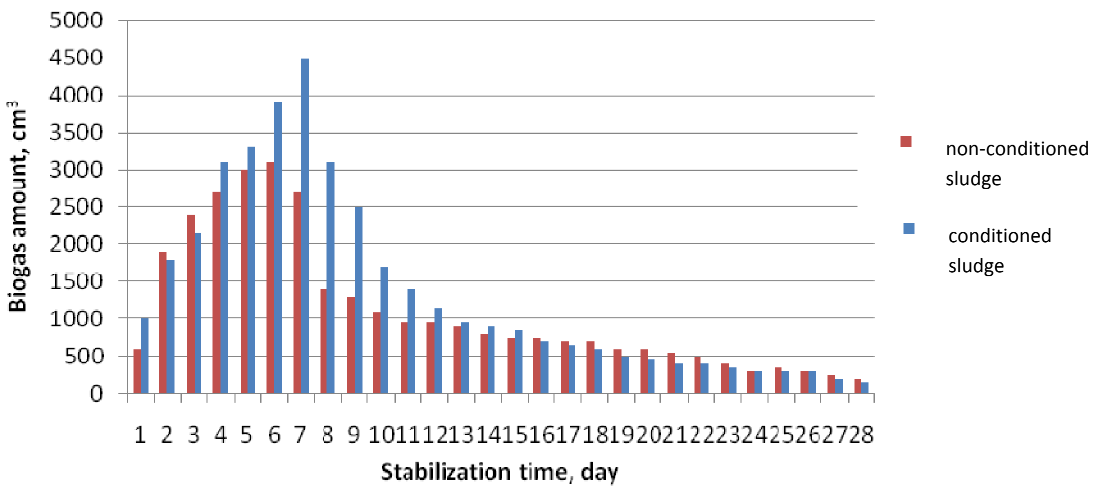

Fig. 2. Biogas generation during stabilization process

The amount of biogas generated during stabilization of the non-conditioned sewage sludge reached the highest level of 3.1dm^3 on the sixth day of the process, whereas the highest amount of the biogas during stabilization of the conditioned sludge was observed on the seventh day of the process, being 4.5 dm^3.

Table 4 presents composition of the biogas which was generated during the stabilization processes.

The highest share of methane in the analysed biogas, being 78.9% CH_4, was observed for both processes on the twelve day of fermentation.

Microbiological analysis of the stabilized non-conditioned sludge and the sludge conditioned with the ultrasound field is presented in Table 5.

TABLE 3
Amount of biogas generated during stabilization process of non-conditioned and ultrasonically conditioned sludge

Duration of anaerobic stabilization process, day	Biogas amount, dm^3	
	Stabilization of sludge conditioned with ultrasonic field	Stabilization of non-conditioned sludge
1	0,1	0,6
2	1,8	1,9
3	2,15	2,4
4	3,1	2,7
5	3,3	3,0
6	3,9	3,1
7	4,5	2,7
8	3,1	1,41
9	2,5	1,3
10	1,7	1,1
11	1,4	0,95
12	1,15	0,95
13	0,95	0,9
14	0,9	0,8
15	0,85	0,75
16	0,7	0,75
17	0,65	0,7
18	0,6	0,7
19	0,5	0,6
20	0,45	0,6
21	0,4	0,55
22	0,4	0,5
23	0,35	0,4
24	0,3	0,3
25	0,3	0,35
26	0,3	0,3
27	0,2	0,25
28	0,15	0,2

TABLE 4
Composition of the biogas which was generated during the stabilization process

Duration of stabilization process, day	Biogas composition after anaerobic stabilization process, %							
	Non-conditioned sludge				Conditioned sludge			
	CH_4, %	CO_2, %	O_2, %	Residual gases,%	CH_4, %	CO_2, %	O_2, %	Residual gases, %
2	33,7	13,8	4	48,5	46,7	17,7	2,8	33,2
4	49,8	25,9	2,3	32	69,1	25,5	0,5	4,9
6	74,1	24,7	0,02	1,4	75,7	26,2	0,03	0
8	76,8	24	0,02	0	76,5	24	0,1	0
10	78,3	22,1	0,01	0	78,6	21,5	0,02	0
12	78,9	21,09	0,01	0	78,9	21,3	0,03	0
14	78,4	21,5	0,04	0	78,3	22	0,02	0
16	77,8	22,1	0,02	0,08	77,1	23,5	0,01	0
20	77,3	22,9	0,02	0	76,2	23	0,02	0,8
24	76,9	21,3	0	1,8	75,7	22,9	0,03	1,4
28	76,2	21,4	0,06	2,4	74,5	22,8	0,04	2,7

TABLE 5
Changes in the microorganisms amount during the stabilization process

Anaerobic stabilization time, day	Amount of microorganisms, JTK/cm^3					
	Non-conditioned sludge			Conditioned sludge		
	mesophilic microorganisms	psychrophilic microorganisms	*Escherichia coli* bacteria	mesophilic microorganisms	psychrophilic microorganisms	*Escherichia coli* bacteria
0	$58 \cdot 10^6$	$43 \cdot 10^6$	10^6	$26 \cdot 10^5$	$22 \cdot 10^6$	10^5
1	$49 \cdot 10^6$	$38 \cdot 10^6$	10^6	$23 \cdot 10^5$	$18 \cdot 10^6$	10^5
5	$20 \cdot 10^6$	$15 \cdot 10^6$	10^5	$14 \cdot 10^4$	$20 \cdot 10^4$	10^4
10	$17 \cdot 10^5$	$22 \cdot 10^3$	10^3	$81 \cdot 10^3$	$15 \cdot 10^4$	10^3
28	$13 \cdot 10^4$	$10 \cdot 10^2$	10^2	$39 \cdot 10^3$	$4 \cdot 10^4$	10^1

Based on the obtained results of the microbiological analysis, the effect of stabilization processes on the changes in the microorganisms amount was presented. On the consecutive days of stabilization, a reduction in microorganisms was observed. These relationships were found both in the non-conditioned sludge and the sludge conditioned with ultrasound field. The highest depletion of mesophilic and psychrophilic microorganisms were obtained during stabilization of the non-conditioned sludge. The decreases in *Escherichia coli* bacteria count were comparable during both stabilization processes.

4. CONCLUSIONS

The following conclusions were drawn based on the obtained results:

- the initial increase in the VFA and COD levels and the decrease in these values during the final stage of stabilization and the reduction in dry mass of the sludge confirmed the processes of biochemical degradation of organic compounds;
- conditioning of the sludge before the process of stabilization caused more intensive generation of biogas, which was the highest on the seventh day of the process of stabilization and reached 4.5 dm^3;
- the higher values of VFA and COD observed during stabilization of the conditioned sludge confirmed more intensive biochemical decomposition of the compounds compared to stabilization of the non-conditioned sludge;
- the conditioned sludge exhibited lower microorganisms count, both during initial and final phase of the process of stabilization.

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WPŁYW POLA ULTRADŹWIĘKOWEGO NA PARAMETRY CHEMICZNE I MIKROBIOLOGICZNE STABILIZOWANYCH OSADÓW NADMIERNYCH

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STRESZCZENIE *Jednym z procesów stosowanych w przeróbce osadów ściekowych jest stabilizacja beztlenowa. Proces ten polega na biochemicznym rozkładzie wielkocząsteczkowych związków przy udziale odpowiedniego typu bakterii. Zastosowanie techniki kondycjonowania osadów przed stabilizacją beztlenową powoduje skrócenie czasu trwania tego procesu.*

Badania prowadzono na osadzie nadmiernym pobranym z oczyszczalni „Warta" w Częstochowie. Osad nadmierny tworzy strukturę niepodatną na stabilizację beztlenową, ma ona bowiem postać aglomerowanych komórek mikroorganizmów mało podatnych na rozkład biologiczny. Zastosowanie czynnego pola ultradźwiękowego w tego rodzaju osadzie powoduje rozerwanie błon komórkowych bakterii, co z kolei przyczynia się do uwolnienia związków organicznych z ich wnętrza. Proces ten zwiększa skuteczność stabilizacji beztlenowej.

Proces stabilizacji beztlenowej prowadzano przez 28 dni w temperaturze 37°C. W pierwszej części doświadczenia stabilizowano osady niepoddane metodzie kondycjonowania, natomiast w drugiej części doświadczenia stabilizację prowadzono po uprzednim zastosowaniu pola ultradźwiękowego o określonych parametrach.

Podczas trwania stabilizacji beztlenowej wykonywano analizy chemiczne, takie jak: sucha masa, sucha masa mineralna, sucha masa organiczna, zasadowość, kwasowość, pH, ChZT, lotne kwasy tłuszczowe, azot amonowy, azot ogólny Kjeldahla, fosfor ogólny. Wykonano również oznaczenia mikrobiologiczne na obecność bakterii typu Escherichia coli, mikroorganizmów psychrofilowych oraz mezofilowych.