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EFFECT OF THERMO-ULTRASONIC DISINTEGRATION OF EXCESS SLUDGE ON THE EFFECTIVENESS OF ANAEROBIC STABILIZATION PROCESS

WPŁYW TERMICZNO-ULTRADŹWIĘKOWEJ DEZINTEGRACJI OSADÓW NADMIERNYCH NA EFEKTYWNOŚĆ PROCESU STABILIZACJI BEZTLENOWEJ

Abstract: It is estimated that processing of sewage sludge absorbs ca 70% of utilization costs. Subjecting initial and secondary sludge to aerobic stabilization, regarded as environment-friendly and economical technology contributes to a considerable minimization of the mass of the sludge. Biogas production is an essential factor which improves the profitability of the process of methane fermentation since it allows for partial recovery of costs incurred for maintenance of mesophilic conditions of fermentation. Methane fermentation is a process which occurs slowly and necessitates a long period of retaining sludge. The degree of fluidization of insoluble organic polymers to soluble form, available for microorganisms, has essential effect on the rate of sludge biodegradation. Disintegration of excess sludge affects the increase in dispersion of sludge particles, which determines acceleration of the process of hydrolysis which limits the course of anaerobic stabilization. Increase in the speed of production of VFAs and increase in their level over consecutive days of acid fermentation preconditions biogas production efficiency. This paper presents the results of the investigations concerning the effect of disintegration by means of a hybrid method on the efficiency of 25-day anaerobic stabilization *ie* the degree of sludge fermentation and intensification of biogas production. Application of thermal-ultrasound excess sludge processing caused the increase in the degree of sludge fermentation, where ca 60% removal of organic dry mass was reported with respect to anaerobic stabilization of raw sludge. Moreover, the increase in intensity of biogas production was observed, expressed in the value of unit biogas production, which amounted to 4.64 dm^3/g of organic dry mass for the sludge subjected to modification by the hybrid method, whereas this value for raw sludge amounted to 1.1 dm^3/g of organic dry mass.

Keywords: excess sludge, ultrasound-thermal disintegration, anaerobic stabilization, degree of sludge fermentation, unit biogas production

Disintegration of sewage sludge consists in destruction of the structure of the sludge through application of external forces which affect changes in their physicochemical parameters and the character of the structure. Due to the origins of implementation of the energy supplied into the system, one can distinguish between mechanical disintegration, which includes the method using ultrasound effect, with sludge particles subjected to shear forces and pressure which cause stress in the structure of sludge and non-mechanical disintegration, eg thermal processing [1].

The effect of ultrasound field and thermal processing on a medium produces the results of mechanical sonochemical nature. Acute conditions (high temperature and pressure) in the area of cavitation explain the changes in physicochemical properties in sonicated systems. The effect of excess sludge conditioning is disintegration, which, apart from dispersion of solid phase in the sludge, causes destruction of cell membranes in microorganisms and release of the substrates contained in the cells to sludge liquid, which

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is essential for further biochemical decomposition of organic compounds. The degree of destruction of the structure of sludge depends on the method, amount of energy supplied and sludge properties [2].

As a result of the process of disintegration, the amount of organic matter which can be processed into biogas is increased. "Killing" the organisms resistant to anaerobic conditions in activated sludge accelerates and intensifies sludge fermentation in fermentation chamber. After the process of anaerobic stabilization, the sludge with lower content of organic matters is obtained. Properly fermented sludge, with low content of organic matter, allows for easier mechanical dehydration. Application of disintegration gives in effects better stabilization and dehydration of the sludge. As a result of decomposition of more organic mass in the sludge into biogas in the process of fermentation, overall amount of sludge for final use is obtained.

The most advanced methods which are used on an industrial scale in sewage treatment plants today include the methods of mechanical disintegration, ultrasounds and thermal sludge treatment [1]. Degree of destruction of sludge structure depends on the applied method, energy and properties of the sludge [3].

In the case of the process of anaerobic stabilization of sewage sludge, an important energy-related problem is intensification of biogas production. Application of pre-conditioning of sewage sludge allows for increase in the degree of fermentation of the sludge subjected to physical modification as well as intensification of biogas production [4].

The processes of anaerobic stabilization contribute to: substantial reduction in the amount of compounds which release unpleasant odour, reduction in the amount of organic matter in the sludge, facilitation of the processes of sludge dehydration and reduction in the amount of pathogens [5, 6].

The aim of the investigations was to determine the effect of initial treatment of excess sludge by means of ultrasound field and the combined (hybrid) ultrasound-thermal method of disintegration on the course of the process of anaerobic stabilization ie the degree of sludge fermentation and biomass production.

Material and methods

A basic substrate for the study was excess sludge (90%), and fermented sludge (10%) which was used for inoculation. The sludge was sampled from the Warta Central Sewage Treatment Plant in Czestochowa. General characteristics of raw excess sludge are presented in Table 1.

Table 1

General characteristics of raw excess sludge

Parameters / Type of sludge	Hydration	Dry mass	Dry org. mass	Dry min. mass	Volatile Fatty Acids (VFAs)	Chemical Oxygen Demand (COD)
	[%]	[g/dm^3]	[g/dm^3]	[g/dm^3]	[mg CH_3COOH/dm^3]	[mg O_2/dm^3]
Excess sludge	98.75	9.51	6.52	2.99	68	120

During the first stage of the investigations, changes in COD were adopted as a criterion of assessment of physicochemical and biomechanical changes which occur in sludge as a result of application of physical methods of conditioning. During the second stage, these parameters were used for determination of the most favourable conditions of conditioning of the sludge with ultrasound field and hybrid ultrasound-thermal method for the process of 1-day and 25-day anaerobic stabilization.

The choice of the most advantageous parameters of disintegration with ultrasound field was made using VCX 1500 disintegrator manufactured by SONICS (USA) with automated tuning. Maximal output power of this generator amounts to 1500 W, with the frequency of sonication of 20 kHz. Sonotrode in this disintegrator was submerged in a container with the diameter of 10 cm containing sludge at the depth of 5 cm from the container's bottom. The volume of the conditioned samples will amount to 0.5 dm^3. In the case of the hybrid ultrasound-thermal method, the sample, after the use of ultrasound field, was closed in laboratory flask with glass plug equipped in fermentation pipe and placed in water bath with automated shaking for the period of 1.5 hours at the temperature of 70ºC.

The sludge prepared in this manner, in the amount appropriate to the process of anaerobic stabilization, was cooled under natural conditions to the temperature of 37ºC, and then inoculated with fermented sludge at the amount of 10% of the whole volume. The mixtures of sludge obtained with this method were very well mixed and used in the process of 10-day acid fermentation carried out in laboratory flasks (V = 0.5 dm^3), which played the role of fermentation chambers, closed with glass plug with fermentation pipe and placed in a thermostat at the temperature of 37ºC. The process of 25-day stabilization was carried out in fermentation chamber with effective capacity of 7 dm^3. The system is equipped in the installation which ensures constant temperature of the process, the equipment which provides optimal mixing rate and installation for biogas sampling. There is a water jacket on the outside of the system, which is used for heating the sludge in the chamber. The required temperature of 37ºC was provided by platinum thermoelectrode placed inside the chamber. Biogas was captured by means of the system which included the cylinder with capacity of 2 dm^3, filled with saturated solution of sodium chloride and compensation bottle with capacity of 5 dm^3. The cylinder allows for reading the amount of generated biogas. The biogas collected in the cylinder lifts the excess liquid from cylinder to the compensation bottle. The control over the course of fermentation was carried out every day based on the measurement of the amount of generated biogas.

On each day of the process (10 days), before the process (0-day) and after fermentation chamber (25th day), the levels of dry mass, organic dry mass and mineral dry mass were determined. Levels of *Chemical Oxygen Demand* (COD) were measured based on dichromate method using spectrophotometer HACH 2100N IS, whereas *Volatile Fatty Acids* (VFAs) levels were measured using the method of distillation with water vapour in supernatant liquor.

Discussion

Initial sludge treatment before the process of fermentation was aimed at disintegration of sludge particles, destruction of microorganisms in excess sludge and release of the organic compounds and enzymes. Based on the results obtained during initial

investigations, with consideration of the changes in COD levels in sludge liquor for excess sludge disintegrated with ultrasound field, the most favourable amplitude and conditioning time was determined. In the case of the hybrid method, time of sludge preparation in water bath after the use of ultrasound field was also determined. It was adopted after the analysis of the obtained results that the most favourable time of sludge preparation with ultrasound field was 10 min, with vibration amplitude of 80% (≈31.4 μm). In order to carry out the process of anaerobic stabilization by means of the hybrid method, the sludge was additionally prepared at the temperature of 70ºC for 1.5 hours in water bath, after the use of ultrasound field.

Changes in parameters for the methods of sludge conditioning discussed above after the process of anaerobic stabilization are presented in Table 2.

Table 2

Selected physical and chemical parameters of physically pretreatment sludge

Fermentation time [d]	**Parameters**	**Unit**	**Raw sludge**	**Ultrasonic field 80% - 10 min**	**Hybrid method 80% - 10 min + 70ºC - 1.5 h**
0	Dry mass	[g/dm^3]	11.2	12	13.6
	Dry org. mass	[g/dm^3]	8.15	8.4	8.6
	COD	[mg O_2/dm^3]	160	2768	3714
	VFAs	[mg CH_3COOH/dm^3]	85	137	124
10	Dry mass	[g/dm^3]	7.25	7.6	8.8
	Dry org. mass	[g/dm^3]	5.71	4.5	5.3
	COD	[mg O_2/dm^3]	145	761	1648
	VFAs	[mg CH_3COOH/dm^3]	51	360	582
25	Dry mass	[g/dm^3]	6.65	6.9	7.7
	Dry org. mass	[g/dm^3]	4.67	3.9	3.6
	COD	[mg O_2/dm^3]	120	300	386
	VFAs	[mg CH_3COOH/dm^3]	42	154	240

The highest level of COD (3714 mg O_2/dm^3) was observed before the process of anaerobic stabilization in the case of hybrid method (mixture C). The recorded level of COD was 23-time higher compared with excess sludge without conditioning (mixture A), with its value reaching 160 mg O_2/dm^3. On the 10th day of methane fermentation, value of COD for sludge conditioned with ultrasound field (mixture B) and hybrid method amounted to, respectively, 761 and 1648 mg O_2/dm^3. After the process in fermentation chamber (25th day), level of COD was 300 and 386 mg O_2/dm^3, respectively for the sludge subjected to ultrasound field and using hybrid method. Figures 1 and 2 present levels of COD and VFA registered on individual days of the process of anaerobic stabilization.

The highest value of VFA which amounts to 1782 mg CH_3COOH/dm^3 was found for the 4th day of anaerobic stabilization of excess sludge disintegrated with hybrid method. In the case of sludge conditioned with the same ultrasound field, the maximal value of 1508 mg CH_3COOH/dm^3 for VFA parameter was obtained on the second day of the process. Comparing the obtained results to sludge which is not physically conditioned, with the highest level of VFA of 497 mg CH_3COOH/dm^3 reported on 4th day, a 3- and 3.5-time rise in VFA level can be observed in the case of ultrasound field and hybrid method, respectively.

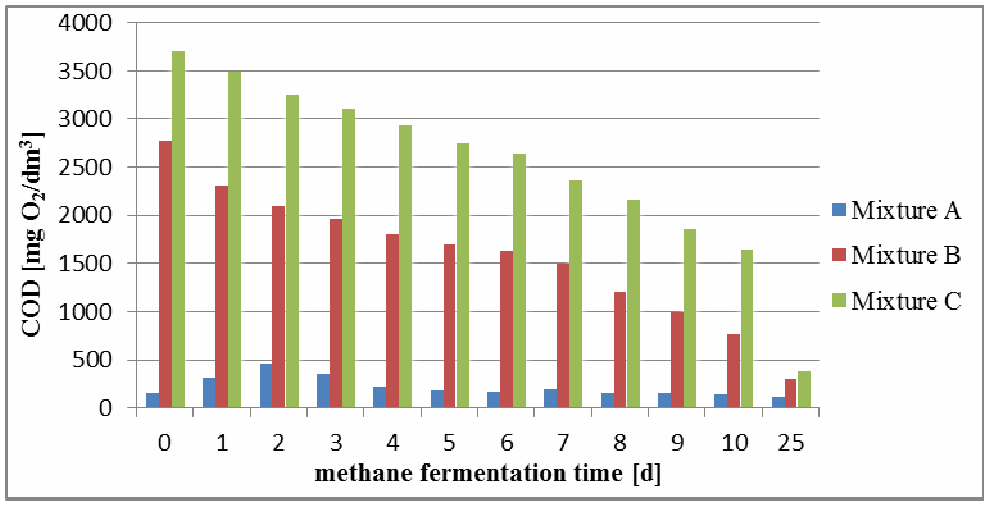

Fig. 1. Changes in the COD level observed in sludge liquor as a function of methane fermentation time

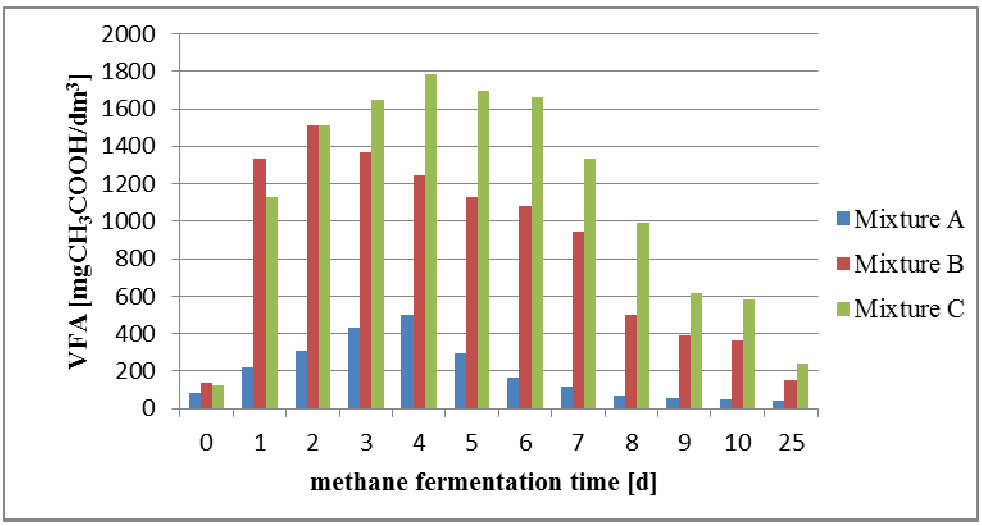

Fig. 2. Changes in the VFAs level observed in sludge liquor as a function of methane fermentation time

For the processes of anaerobic stabilization, the degree of sludge fermentation was also determined based on depletion of organic matter. The obtained levels of dry mass and organic dry mass on consecutive days of the process are presented in Figures 3 and 4.

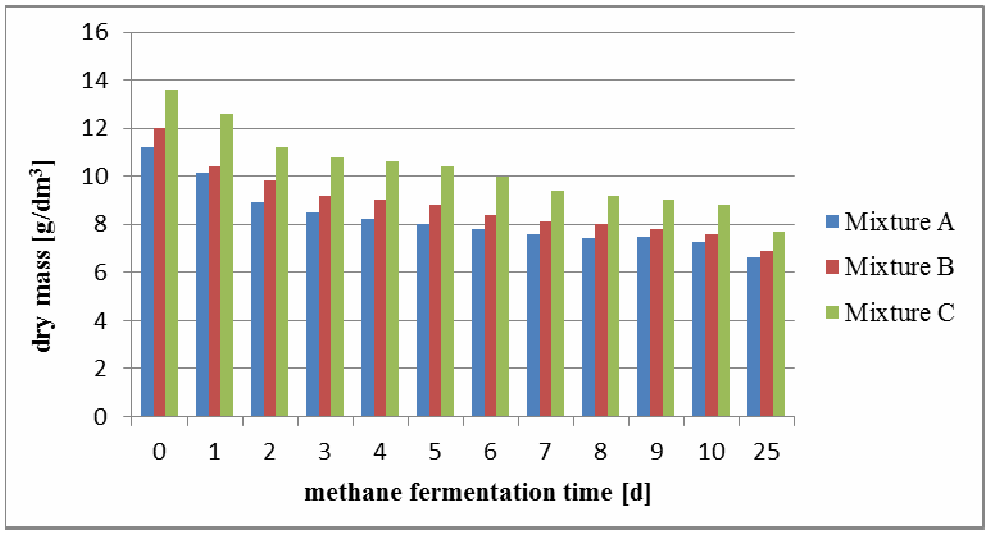

Fig. 3. Changes in the dry mass level observed in sludge liquor as a function of methane fermentation time

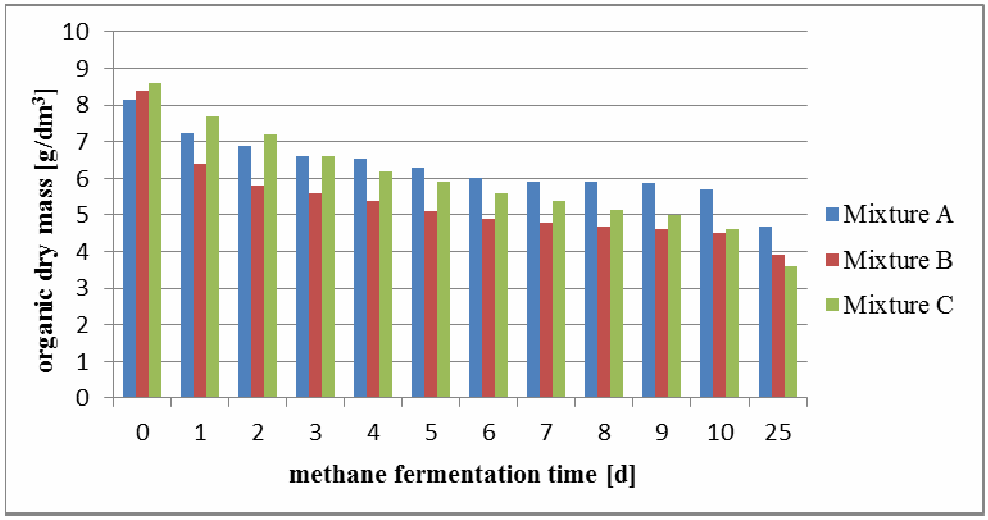

Fig. 4. Changes in the dry organic mass level observed in sludge liquor as a function of methane fermentation time

The highest degree of sludge fermentation using the hybrid method (mixture C) (ca 60%) was obtained after the process of 25 day anaerobic stabilization, whereas in the case of the sludge conditioned with ultrasound field (mixture B), a 53% decrease in organic dry matter was reported. The degree of fermentation for the non-prepared sludge amounted to 42%.

Furthermore, the degree of fermentation after the process of 10-day anaerobic stabilization amounted to 29, 46 and 47% for A, B and C mixture, respectively. Essential effect in terms of economics of the process of anaerobic stabilization is from the amount of generated biogas, which can be exchanged into electricity or used for heating fermentation chambers. This causes considerable reduction in the costs of maintaining sewage treatment plants. The highest total biogas production of 23.23 dm^3 was observed during the process of hybrid method carried out in fermentation chamber (25 days).

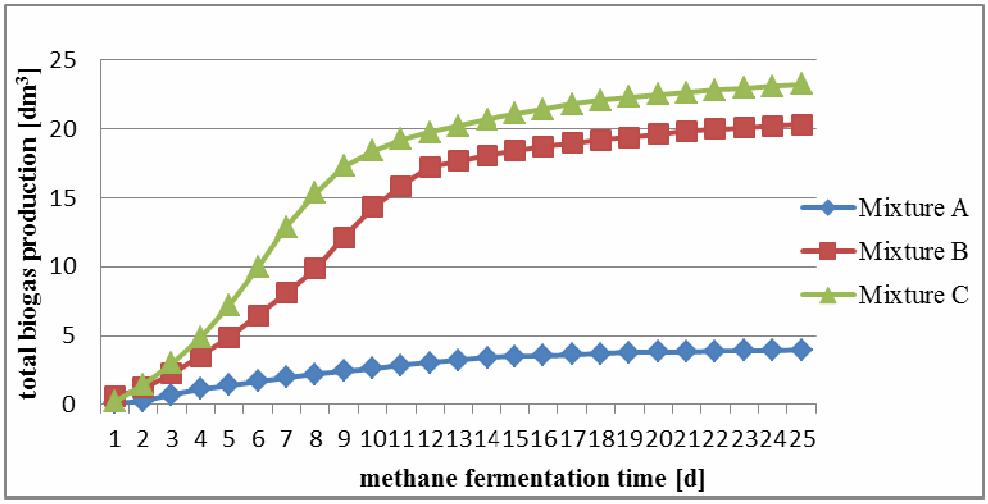

Fig. 5. The total biogas production in anaerobic stabilization process

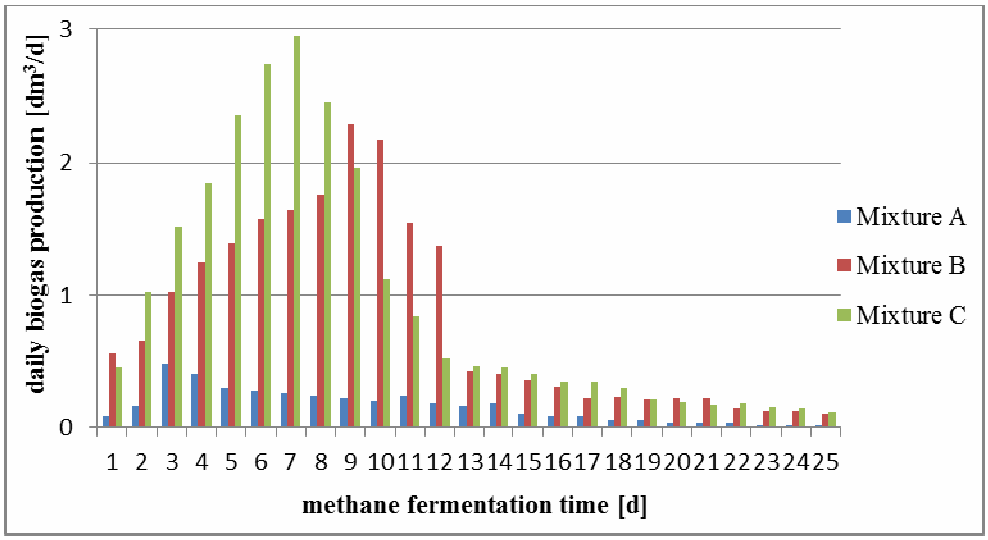

Fig. 6. Daily biogas production in anaerobic stabilization process

In the case of sludge conditioned with ultrasound field (mixture B), the total value of the obtained biogas amounted to 20.31 dm^3, whereas this value for non-prepared sludge was only 3.94dm^3. Total biogas production is compared in Figure 5.

The highest daily biogas generation (2.95 dm^3/d) was observed on the 7th day of the process for the sludge subjected to preparation with the hybrid method. In the case of the sludge conditioned with ultrasound field, the highest level of daily biogas generation (2.28 dm^3/d) was reported on the 9th day of the process. For non-conditioned sludge, the highest level of biogas generation per day was 0.48 dm^3/d. Daily biogas generation levels are presented in Figure 6.

A unit biogas generation was also calculated based on biogas generation. The highest value of unit biogas generation of 4.64 dm^3/g of *organic dry mass* (o.d.m.) was obtained in the case of hybrid method. Similar high value of unit biogas generation was observed in the sludge conditioned with ultrasound field (4.51 dm^3/g o.d.m.). Raw excess sludge exhibited unit biogas generation at the level of (1.13 dm^3/g o.d.m.).

Conclusions

The process of initial conditioning leads to an increased degree of excess sludge disintegration, which is reflected by an increase in concentration of organic compounds in sludge liquor. Increase in concentration of soluble organic matter contributes to intensification of hydrolytic phase of the process of methane fermentation. With an increase in the degree of fragmentation of solid phase of the sludge, their susceptibility to biodegradation is substantially increased.

The following conclusions can be drawn based on the results obtained in the study:

- Application of conditioning before the process of anaerobic stabilization facilitates operation of the separated chambers of fermentation, which provides benefits in the form of increased biogas generation, higher degree of sludge fermentation and shortening the process of methane fermentation.
- Both in the case of conditioning of sludge with ultrasound field and hybrid method, a considerable degree of fermentation and intensification of biogas production can be obtained.
- The investigations carried out using a hybrid method, where the highest levels of COD and VFA, degree of fermentation and increased biogas production were observed confirm the legitimacy and effectiveness of the selected method.

Acknowledgments

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References

[1] Arbeitsbericht der ATV-Arbeitgruppe 3.1.6, 2000, Klaerschlammdesintegration - Teil 1: Verfahren und Anwendungsgebiete der mechanischen Klaerschlammdesintegration. KA, 4/2000, 570-576.

[2] Zielewicz-Madej E. The influence of ultrasonic field on fatty acid production and phosphorus discharge in hydrolysis of sewage sludge. Mat. XLIV "Otwarte Seminarium Akustyki - OSA". Gdańsk - Jastrzębia Góra: 1997, 691-694.

[3] Zielewicz-Madej E, Fukas-Płonka Ł. Nowoczesny ciąg technologiczny przeróbki osadów ściekowych nadmiernych. Gospodarka Odpadami Komunalnymi. 2006;2:169-186.

[4] Elpiner JE. Ultradźwięki, działanie fizykochemiczne i biologiczne. Warszawa: Wyd Nauk PWN; 1992.
[5] Bień JB. Osady ściekowe - teoria i praktyka. Częstochowa: Wyd Polit Częstochow; 2002.
[6] Łomotowski J, Szpindor A. Nowoczesne systemy oczyszczania ścieków. Warszawa: Arkady; 2002.

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Abstrakt: Szacuje się, że przeróbka osadów ściekowych pochłania ok. 70% kosztów eksploatacyjnych oczyszczalni. Poddanie osadów wstępnych i wtórnych stabilizacji beztlenowej, uważanej za technologię zarówno przyjazną środowisku, jak również ekonomiczną, przyczynia się do znacznej minimalizacji masy osadów. Produkcja biogazu stanowi istotny czynnik zwiększający rentowność prowadzonego procesu fermentacji metanowej, ponieważ pozwala na częściowy odzysk kosztów ponoszonych na utrzymanie mezofilowych warunków fermentacji. Fermentacja metanowa to proces przebiegający wolno oraz wymagający długiego okresu zatrzymania osadów. Stopień upłynnienia nierozpuszczalnych polimerów organicznych do postaci rozpuszczonej, dostępnych dla mikroorganizmów, ma znaczący wpływ na szybkość biodegradacji osadów. Dezintegracja osadów nadmiernych wpływa na wzrost dyspersji cząstek osadów, co determinuje przyspieszenie procesu hydrolizy, limitującej przebieg stabilizacji beztlenowej. Zwiększenie szybkości wytwarzania LKT oraz wzrost ich wartości w kolejnych dobach kwaśnej fermentacji warunkuje bezpośrednio efektywność produkcji biogazu. W artykule przedstawiono wyniki badań dotyczące wpływu dezintegracji prowadzonej metodą hybrydową na efektywność 25-dobowej stabilizacji beztlenowej, tj. wzrost stopnia przefermentowania osadów oraz intensyfikację produkcji biogazu. Zastosowanie termiczno-ultradźwiękowej obróbki osadów nadmiernych wpłynęło na wzrost stopnia przefermentowania osadów, gdzie odnotowano ok. 60% usunięcie s.m.o. w odniesieniu do stabilizacji beztlenowej osadów surowych. Ponadto zaobserwowano wzrost intensywności produkcji biogazu, czego wyrazem była wartość jednostkowej produkcji biogazu wynosząca dla osadów poddanych modyfikacji metodą hybrydową 4,64 dm^3/g s.m.o_u, natomiast dla osadów surowych 1,1 dm^3/g s.m.o_u.

Słowa kluczowe: osady nadmierne, dezintegracja termiczno-ultradźwiękowa, stabilizacja beztlenowa, stopień przefermentowania osadów, jednostkowa produkcja biogazu