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A – study design
B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

Impact of microwave radiation on the process of aerobic digestion of sewage sludge

Justyna CZAJKOWSKA ABDEF ✉, Maciej MALARSKI ABDE, Piotr NOWAK ABDF, Tadeusz SIWIEC ABDE

Warsaw University of Life Sciences, Faculty of Civil and Environmental Engineering, ul. Nowoursynowska 159, 02-776 Warsaw, Poland; e-mail: justyna_czajkowska@sggw.pl

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Abstract

The process of aerobic stabilization of sludge is a process used in small or medium sewage treatment plants (up to 15 000 ENI). Owing to its energy intensity resulting from the need for intensive sedimentation and long-term process, many researches are being conducted on its intensification. One such method is disintegration. The purpose of disintegration is to increase the susceptibility of sewage sludge to aerobic decomposition by breaking up sediment flocs into fine particles along with the breakdown of cell membranes and then allowing biodegradation. The paper presents results of research of aerobic stabilized sludge, which is a mixture of non-disintegrated and microwave disintegrated sludge in different volume proportions. It was shown that sludge stabilized more quickly during the first days of the process.

The minimum reduction of organic solids required at 38% for stabilized sludge occure earlier in mixed sludge tests than in non-disintegrated sludge.

Key words: *aerobic stabilization, disintegration, dry organic matter, microwaves*

INTRODUCTION

Preliminary and excessive sludge produced during wastewater treatment processes should be stabilized so that they do not crumble and do not pose a threat to the environment. This is necessary even though the costs of stabilization and disposal are high and can account for up to 60% of total operating costs in sewage treatment plants [LOW *et al.* 2000].

Stabilization of sewage sludge is one of the most important stages in their treatment processing. It can be aerobic or anaerobic process. It is a process in which organic matter is decomposed by microorganisms. The efficiency of these processes is determined by the rate of hydrolysis, which is considered to be a step limiting the speed of the whole stabilization process. In order to accelerate hydrolysis and thus improve the course of stabilization processes, a number of methods, called disintegration processes are used. Among the disintegration methods are: mechanical (homogenization, ultrasound, microwaves), chemical (ozone, acid and alkaline hydrolysis), biological (enzymes, autolysis, fungi, bacteria), thermal (low temperature, high temperature). The main aim of pretreatment methods is to dissolve and reduce the size of the organic compound particles so that they are more susceptible to biological degradation [SADECKA 2010; YANG *et al.* 2013]

Sludge removal should be part of the sewage concept in order to use all possible means and solutions aimed at reducing the amount of sludge, improving their quality, minimizing costs and their final removal [BAUMAN-KASZUBSKA, SIKORSKI 2009]. In Poland, one of the most commonly used methods of sewage sludge management is their incineration and storage. This is an irrational way to handle sewage sludge containing large amounts of organic matter and nutrients [AUGUSTYNOWICZ *et al.* 2010; JAKUBUS 2006].

Pre-treatment methods (including disintegration), although they increase the rate of stabilization, often generate high operating and maintenance costs. They cause corrosion problems, and often long response time limits the practical application of these techniques. Some of the studies described in the literature focused on the use of microwave radiation for environmental engineering applications, mainly because using microwave heating and the desired temperature can be achieve faster and it uses less energy [ISKRA, MIODOŃSKI 2014; YANG *et al.* 2013].

The mechanism of microwave interactions on the sludge consists of two effects: thermal and non-thermal. The thermal effect is caused by the interaction of a variable electrical field with dipolar particles such as water, proteins, fats, and other organic particles. This causes the particles to rotate and eventually lead to the sludge heating. The non-thermal effect is attributed to dipoles that rapidly change the orientation in the polarized side chains of the macromolecules, giving the possibility of breaking hydrogen bonds. As a result of this process occurs disintegration of flocks and change in secondary and tertiary structures of proteins in the cell membrane of microorganisms, which in turn leads to their death [APPELS *et al.* 2013; ESKICIOGLUA *et al.* 2007; HOUTMEYERS *et al.* 2014].

In small and medium sewage treatment plants aerobic stabilization is often used as an effective method of decomposing organic readily decomposable substances. This investment-saving method generates high operating costs resulting from the need for long-term aeration of sludge. For this reason, many laboratories are conducting research on the acceleration of the aerobic stabilization process using a variety of methods so as to reduce the energy consumption of the blower as a source of oxygen during sludge aeration [LIU *et al.* 2011; ZHU *et al.* 2017].

The purpose of this paper is to determine the influence of microwave disintegration on the kinetics of aerobic stabilization of sewage sludge to estimate the possibility of shortening their stabilization time.

MATERIALS AND METODS

The sewage sludge from the "Mokre Łąki" sewage treatment plant in district of Izabelin was used. This is a treatment plant that use the active sludge method. The excessive sludge was collected in the period from December 2016 to January 2017 from the pumping station after the secondary settling tank and then was transported to the Laboratory of Water and Wastewater Treatment of WULS-SGGW.

Sludge that has been transported from the sewage treatment plant, was concentrated by removal of the supernatant liquid in amounts of 40% of the accessible volume. The concentrated sludge was divided into two portions. The first one was a control sample (non-disintegrated sludge) and its volume was 15 dm^3. The second one was partly disintegrated in ratio 1:1 of the non-disintegrated to the disintegrated sludge at first series of experiment, and in ratio 0:1 at second series of experiment. So to obtain a sample of 15 dm^3 at first series, 7.5 dm^3 of non-disintegrated sludge was mixed with 7.5 dm^3 of disintegrated sludge, and at second series 15 dm^3 of disintegrated sludge was used. Such sludge samples were placed in identical aeration tanks (stabilized) with aeration kit consisting of an 8 W pump and aeration aerosol as a filter.

The sludge was disintegrated using a microwave oven with a power of 700 W and a frequency of 2.45 GHz. The sludge was disintegrated in 0.5 dm^3 portions over 4 min. The optimum disintegration time for sludge from the "Mokre Łąki" sewage treatment plant has been established in previous studies [CZAJKOWSKA, KAZIMIERCZAK 2016].

The sludge for the first of the described series was collected on 13th January 2017. 15 dm^3 of concentrated, raw, non-disintegrated sludge (it was a control sample) was placed into the tank "I". The second portion of mixture of non-disintegrated and disintegrated sludge in a 1:1 ratio was placed into the tank "II" (7.5 dm^3 of raw concentrated sludge and 7.5 dm^3 of disintegrated sludge).

The sludge of the second described series was taken on 20th December 2016. 15 dm^3 of concentrated, raw, non-disintegrated sludge (control sample) was placed in the tank "III" and the second portion of completely disintegrated sludge was placed in the tank "IV" (15 dm^3 disintegrated sludge).

After preparing the samples a portion of each supernatant liquid was collected and determined by:
- turbidity – nephelometric method [PN-EN ISO 7027: 2003, chapter 6] using turbidity meter a 2100N IS Turbidimeter,
- pH – electrometric method [PN-EN 10523: 2012] using the Eutech Instruments pH 510 meter and Elmetron IJ44C electrode,
- COD – titrimetric method [PN-ISO 6060: 2006],
- BOD_5 – WTW bottle method using the OXI-TOP set, according to the standard [PN-EN 1899-1: 2002].

To evaluate the impact of disintegration on the sludge liquid, the same parameters were also determined after the end of the test cycle on the 35th day of stabilization.

The stabilization process was carried out for 34 days. The temperature of the stabilized precipitate was 16 ± 1°C. Control parameters of the stabilization process were dry solids [PN-EN 14346: 2011] and total organic solids [PN-EN 15169: 2011] during the tests – they were measured every two or three days. They represented an image of organic solids loss in the process. In addition, during stabilization (once a week), the concentration of dissolved oxygen was measured using the Elmetron oxygen meter CO-505 according to PN-EN 25813: 1997P.

To have an opportunity to calculate the efficiency of a process from a dependency function, the R^2 determinant was used as the search criterion. It was assumed that a good fit would be the same for all cases where the sum R^2 would be the greatest. Such a function is a linear dependence.

These functions have been used to calculate the decomposition efficiency of organic compounds using formula (1):

$$\eta = \frac{S_p - S_i}{S_p} \quad (1)$$

where: η = removal efficiency of organic compounds, S_p = concentration of organic compounds at the beginning of the process, S_i = concentration at appropriate times of the test.

RESULTS AND DISCUSSION

The test results consisted of two parts. One was the analysis of the supernatant liquid before the start of the aerobic stabilization process and at the end of the process, that is on the 35th day. The second part was the results of dry solids and total organic solids analysed on selected days. That was a measure of progress of the process. Tables 1 and 2 show the values of parameters determined in supernatant liquid, and in Tables 3 and 4 of dry solids and total organic solids concentration in aerobic stabilization processes with different ratio of disintegrated sludge.

All of the tested supernatant liquid indicators from the first day of the experiment (initial) shown in Table 1 and 2 in the mixed sample are significantly higher than those for the control sample. It follows that some impurities from the disintegration process pass to the supernatant liquid. After the stabilization process in both tests, the control one and the mixed one, it was observed the BOD_5 value decrease. This is due to the depletion of the easily decomposable organic substance and the increase of turbidity. The exception is BOD_5 (Tab. 2), where value increased from 14.8 mg $O_2 \cdot dm^{-3}$ on the first day of the process to 21.3 mg $O_2 \cdot dm^{-3}$ at its end. For COD in mixed trials, a downward trend has been observed. The value before stabilization is higher than after that. Because of low pH value, COD values at the end of the stabilization process in the control samples were not determined. The downward trend is also characteristic for pH values. In all samples, the pH at the beginning of the process is higher than at the end of the process.

Table 1. Results of the supernatant liquid value for control sample I and mixed in ratio 1:1 for sample II

Indicator		Control sample I	Mixed sample 1:1 II
COD mg $O_2 \cdot dm^{-3}$	initial	60.6	718.3
	final	–	136.4
BOD_5 mg $O_2 \cdot dm^{-3}$	initial	11.5	327.0
	final	2.6	4.7
Turbidity, NTU	initial	8.45	115.00
	final	36.00	17.60
pH	initial	7.15, t = 15.6°C	7.43, t = 21.4°C
	final	4.24, t = 16.8°C	6.6, t = 17.5°C

Source: own study.

Table 2. Results of the supernatant liquid value for control sample III and mixed in ratio 0:1 for sample IV

Indicator		Control sample III	Mixed sample 0:1 IV
COD mg $O_2 \cdot dm^{-3}$	initial	89.7	1 882.4
	final	–	750.1
BOD_5 mg $O_2 \cdot dm^{-3}$	initial	14.8	779.0
	final	21.3	17.5
Turbidity, NTU	initial	4.54	155.0
	final	31.60	339.0
pH	initial	6.75, t = 17.2°C	7.32, t = 27.3°C
	final	5.05, t = 16.8°C	6.19, t = 17.8°C

Source: own study.

Table 3. Dry solids (DS) and total organic solids (TOS) concentrations during aerobic stabilization in a control sample and a mixed sludge sample in ratio 1:1

Day	Control sample		Mixed sample 1:1	
	I DS, g·dm^{-3}	Iorg TOS, g·dm^{-3}	II DS, g·dm^{-3}	IIorg TOS, g·dm^{-3}
1	15.18	11.33	14.43	10.70
4	13.87	10.11	13.44	9.81
6	13.30	9.63	13.02	9.46
8	12.29	8.77	12.56	8.98
11	12.08	8.54	11.95	8.40
13	12.00	8.43	11.49	8.03
15	11.90	8.33	11.23	7.75
18	11,98	8,34	10.75	7.36
20	11.30	7.87	10.07	6.85
22	11.30	7.79	9.98	6.69
25	10.74	7.39	9.49	6.32
27	10.26	6.98	7.86	5.19
29	10.29	7.06	8.83	5.86
32	10.05	6.89	9.32	6.15
35	9.68	6.57	9.29	6.10

Source: own study.

Table 4. Dry solids (DS) and total organic solids (TOS) concentrations during aerobic stabilization in a control sample and a mixed sludge sample in ratio 0:1

Day	Control sample		Mixed sample 0:1	
	III DS, g·dm^{-3}	IIIorg TOS, g·dm^{-3}	IV DS, g·dm^{-3}	IVorg TOS, g·dm^{-3}
1	14.10	10.07	14.05	9.99
4	10.32	7.18	11.70	7.64
8	13.05	8.96	10.86	7.34
11	11.93	8.19	10.75	7.19
14	11.33	7.82	10.61	7.14
17	11.34	7.71	9.82	6.45
21	11.01	7.56	9.74	6.43
23	10.66	7.11	9.26	5.93
25	9.41	6.12	10.27	6.94
28	9.60	6.33	8.85	5.62
30	9.44	6.26	8.76	5.54
32	9.11	6.01	8.64	5.41
35	8.98	5.95	8.48	5.37

Source: own study.

The oxygen concentration in all stabilized sludge was maintained at 7–9 mg O_2·dm^{-3}at sludge temperature in the range of 15–17°C.

According to the results for both described series shown in Tables 3 and 4, the dry solids (DS) and total organic solids (TOS) in sludge that have been aerobic stabilizated for both samples, the control one and the mixed one, decreases in the consecutive days of stabilization. In the case of a 1:1 mixed test II and corresponding test I, it can be seen that the initial concentrations of the test parameters are higher than in the 0:1 test IV (and its control sample III). In the case of control trials, the dry solids concentration at experiment with mixed test in ratio 1:1 was 15.18 g·dm^{-3}, and for the experiment with ratio 0:1 control sample was 14.10 g·dm^{-3}. This fact can be explained by the varying composition of sludge resulting from the different sludge recovery time from the sewage treatment plant. In the case of experiment with ratio 1:1 the sludge was taken from the plant on 13th January 2017, while in the case of ratio of 0:1 it was 20th December 2016.

Analysis of the decomposition efficiency of organic substances (TOS) was based on the analysis of Iorg, IIorg, IIIorg and IVorg values in Tables 3 and 4. To minimize the impact of analytical errors, an attempt was made to approximate the measurement points with different functions. The best reflecting of points was obtained by hyperbolic functions. For this reason, the graphs shown in Figure 1 were constructed where the vertical axis was the reciprocal of organic solids (1/Sorg) and the horizontal stabilization time.

The efficiency of individual processes is shown in Figure 2.

As it can be seen from Fig. 2 points at functions IIorg and IVorg derived from the disintegrated samples lie higher than the Iorg and IIIorg reference samples. This is particularly evident in the process (I–II), when the sludge is partially disintegrated. Performance at 38% [BARTKOWSKA 2015; PODEDWORNA, UMIEJEWSKA 2008] estimated from the established equation is achieved in Iorg after 35.9 days, IIorg at 23.9 days, IIIorg at 37.9 days, and IVorg at 33.5 days. It is interesting to note why disintegration of the whole sludge is less effective in stabilizing it than in the ratio 1:1. Probably this is due to an erroneous measurement of the starting point, which in the future will need to be eliminated. Because the tests consisted of dry solids and dry solids after roasting, it was possible that during the disintegration process the temperature riseing caused the emission of all volatile substances released into the air during microwave destruction. At that time, IIIorg's initial organic solids was artificially underestimated, which automatically overtook each other. That's the reason of underestimated in the calculation efficiency of the process.

According to article by CZAJKOWSKA and KAZIMIERCZAK [2016] a 38% reduction of organic dry solids should be obtained after 13 days of the process conducted at a settling temperature of about 20°C for the ratio 1:1. It is therefore possible to notice the high temperature effect on the rate of decomposition of organic matter.

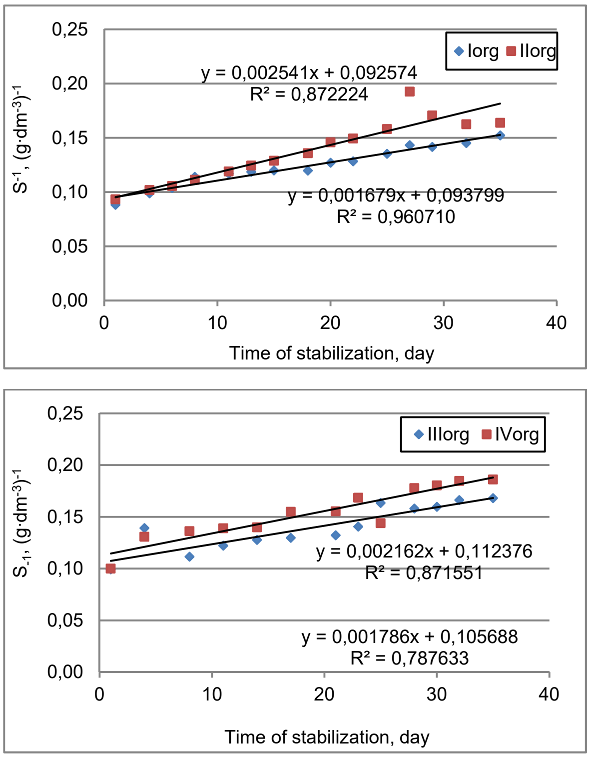

Fig. 1. Hyperbolic dependence of organic solids concentrations as a function of process time; source: own study

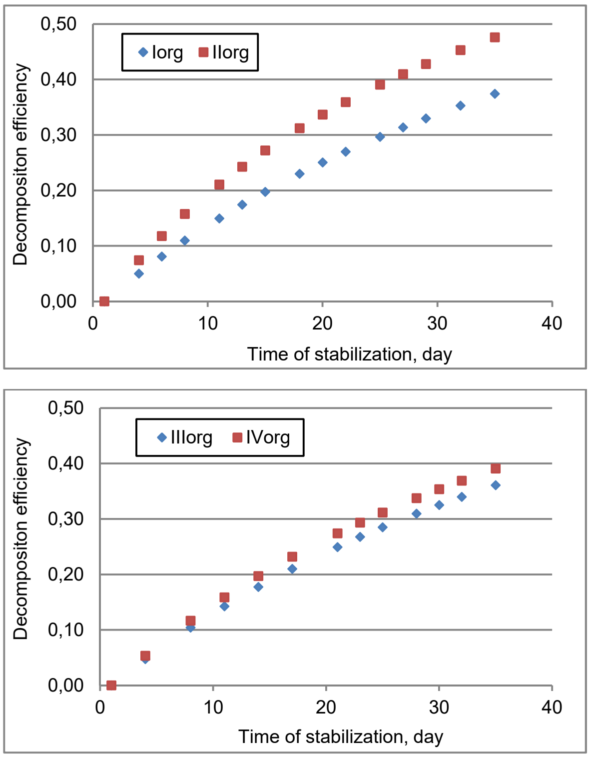

Fig. 2. Effectiveness of organic solids decomposition according to time; source: own study

CONCLUSIONS

Conducted research on basic quality indicators determined in supernatant liquid non-disintegrated sludge (control sample) proves high variability of sludge quality from sewage treatment plants. The COD values of the supernatant liquid control samples of stabilized sludge determined for the tested batches before the stabilization process are 60.6 and 89.7 mg $O_2·dm^{-3}$. BOD values before the stabilization process remain fairly close in scope and are 11.5 and 14.8 mg $O_2·dm^{-3}$, respectively. In the case of turbidity, the increase of its value after the stabilization process has been observed, which is a disadvantage from the operational point of view. The increase in turbidity deteriorates the quality of the superabsorbent liquid that is recycled to the biological wastewater treatment system. Also, a decrease in the pH value to about pH = 4 (acidic environment) negatively affects the quality of the supernatant liquid that is normally recycled to the biological part of the treatment plant and can interfere with nitrification and denitrification processes for optimum pH values.

Sludge stabilization studies have shown a beneficial effect of the disintegrated sludge contribution on the time of the required 38% reduction in organic dry solids. Both in 1:1 ratio as well as 0:1 ratio settling sludge containing 38% disintegrated sludge were obtained previously compared to the control sample. Nevertheless, a significant influence of the process temperature can be noticed.

In the case of the investigations conducted at a settling temperature of about 16°C, the same reduction as in literature for the mixed sample in the same ratio calculated on the basis of the determined functions was obtained for approx. 24th day (IIorg) of the process and for the control sample 36th day trial (Iorg) of the process.

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Justyna CZAJKOWSKA, Maciej MALARSKI, Piotr NOWAK, Tadeusz SIWIEC

Wpływ promieniowania mikrofalowego na proces tlenowej stabilizacji osadów ściekowych

STRESZCZENIE

Proces tlenowej stabilizacji osadów ściekowych jest stosowany w małych lub średnich oczyszczalniach ścieków (do 15000 RLM). Ze względu na swą energochłonność, wynikającą z konieczności intensywnego natleniania osadu i długotrwałości procesu, w wielu miejscach prowadzone są badania nad jego zintensyfikowaniem. Jedną z metod jest dezintegracja. Celem dezintegracji jest zwiększenie podatności osadów ściekowych na rozkład tlenowy przez rozbicie kłaczków osadu na drobne cząstki wraz z rozpadem błon komórkowych i wówczas umożliwienie biodegradacji. W pracy przedstawiono wyniki badań osadu stabilizowanego tlenowo, który jest mieszaniną osadu niezdezintegrowanego i poddanego dezintegracji mikrofalowej w różnej proporcji objętościowej. Wykazano, że osad dezintegrowany mikrofalowo szybciej się stabilizował, szczególnie w pierwszych dniach procesu.

Wymagane minimalne zmniejszenie suchej masy organicznej dla osadu ustabilizowanego na poziomie 38% w przypadku prób osadu mieszanego następowało wcześniej niż w przypadku osadu nie poddanego dezintegracji.

Słowa kluczowe: *dezintegracja, mikrofale, stabilizacja tlenowa, sucha masa organiczna*