DISINTEGRATION OF FERMENTED SLUDGE – POTENTIAL GAINS

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ABSTRACT
Implementation of disintegration of sludge in WWTPs operation improves overall recovery of energy and materials from treated wastewater. Increased net biogas production and thus better energetic characteristics of the plant are recognized as the most important reasons to apply disintegration to the wastewater sludges; usually it is applied for wasted activated sludge (WAS) prior to its mesophilic fermentation. This paper summarizes first stage of laboratory tests on disintegration of fermented (digested) sludge addresses towards more efficient methane recovery and better stabilization. Respirometric tests on digested sludge from full-scale plants showed possibility of increase of total recovery of fermentation gas. Methodology presented has been tested on sludge from large (500000 p.e.) municipal wastewater treatment plant from Cracow, Poland. Ultrasound disintegration method was chosen as a reference; however any of disintegration technology can be tested with the use of proposed procedure.

KEYWORDS
biogas, disintegration, energy recovery, sludge digestion, sludge processing, ultrasound

INTRODCUTION

The sustainability of modern urban systems includes need for wastewater treatment plant improvement in term of potential energy and resource recovery. It led to more emphasis on enhancing an efficiency of anaerobic digestion as the standard technique to sludge stabilization process. The most popular methods of sludge disintegration used in sludge processing include: mechanical (ultrasounds and ball mills) physical (thermal) and chemical (ozonation) methods. Most of tests on disintegration of stabilized sludge being completed in recent years focused on improved dewaterability and minimization of wet mass of sludge rather than ecological safe (stability) and potential biogas recovery. Expected gains of this process are described in literature widely (Müller,et.al.1998, Tiehm et al., 2001, Ödegard 2004, Boehler&Siegrist 2006, Nickel& Neis 2007):

- Increased net biogas production and thus better energetic characteristics of the sludge handling system;
- Possible use of organic matter obtained from a disintegrated WAS as a source of easy biodegradable carbon for denitrification process;
- Minimization of a sludge bulking effect in WWTPs
- Recently, the sludge disintegration processes has appeared as a promising method to enhance the effect of anaerobic stabilization of sludge.

In this paper author tried to apply a disintegration of fermented sludges to verify possible increase of a sludge stabilization process in an anaerobic digester. An ultrasound method to disintegrate sludge has been chosen.

Ultrasound disintegration of sludge flocs can transform a significant part of insoluble organics into a soluble form (Müller 2000, Bougrier et.al.2005). The mechanism of sludge particle disruption

during sonication is still being examined. Hence, the correlation among cavitation bubbles, ultrasound parameters and sludge disruption is not fully developed.
The ultrasonic disintegration effects are a function of many different parameters and the most important groups of parameters are: device and system configuration, medium (sludge) characteristic (Tiehm et al., 2001; Gonze et al., 2003).

MATERIALS and METHODS

Basic concept of measurements

General concept of experiments testing was chosen based on general principle to observe sludge activities in overall conditions as closed to routine operation of sludge digesters as possible. Author found respirometric tests most applicable to present the effect of disintegration of recirculated digested sludge. Sludge from full scale Kraków Kujawy wastewater treatment plant (500000 p.e.) was transported to the University lab for disintegration and testing. The duration of measurements of each series equals to SRT in real digestion chambers (i.e. 21 days). Microscopic analyses of sludge before and after disintegration were performed parallel with gas measurement.

Experimental protocol

Two series of tests were performed: they differed in sonication time: 5, 7 and 9 minutes respectively. Sludge samples were disintegrated using sonic equipment UD 11, nominal frequency 22,5 kHz. Sonication intensity equalled to $24*10^3$ W/m^2, this value was chosen as optimal for this sludge in previous experiments by authors, as well as sonotrode positioning (Cimochowicz-Rybicka et al. 2008). After disintegration, the concentration of COD in supernatant was determined after centrifugation (15 minutes at 5000 rpm) and filtration (paper filter 0.45 μm). The degree of sludge disintegration was calculated by determining the chemical oxygen demand (COD) in sludge supernatant (equation 1). A reference value i.e. the 100% disintegration degree was defined as the COD of supernatant obtained from sludge treated with 1.0 mol/L sodium hydroxide for 22 hours at 20^{o}C (Müller et.al.1998, Gonze et.al.2003).

$$DD = \frac{COD_d - COD_i}{COD_a - COD_i} * 100\% \qquad (1)$$

Where:

COD_d - COD of the centre of the disintegrated sludge sample;
COD_i - initial COD of the centrate of the original sludge sample
COD_a – the maximal value of COD, which can be obtained in the supernatant after alkaline hydrolysis of the sludge; (chemical disintegration with 1 M NaOH).

Furthermore, samples were located in 500 mL gas tight vessels of the AER-208 respirometry tests stand. Vessels were located in water bath with magnetic stirrers ensuring complete mixing to perform test conditions as close to real terms as possible.
Gas generated in vessels was passing through the measuring cells and was checked each two hours continuously with data being stored in the integral computer of the test stand. Methane content in the fermentation gas was checked three times during each of tests series. Eight cell tests stand allowed to perform parallel tests i.e. each sludge sample after sonication was poured to two vessels to perform complete the same procedure, comparison of results allowed to check accuracy of measurements (exclusion of results if specific difference of results exceeded 10 percent of measured value). Remaining process parameters were as close to real ones as possible. The incubation temperature was 35^{o}C. With regard to the sensitivity of methanogenic bacteria to pH, this parameter

was restrictedly controlled in samples and ranged from 7 to 7.4. General arrangement of the test stand was shown on photograph – Figure 1 (next page).

RESULTS AND DISCUSSION

Part I – tests on potential gas production

Experiments were conducted on real digested sludge (19 – 21 SRT). The WWTP serves area inhabited by half million citizens without significant impact of seasonal change on raw wastewater quality. Disintegration degree was 15 percent for sonication time 5 minutes, 28 percent after 7 minutes sonication and remained almost stable as it was 29percent after 9 minutes' sonication. Gas production was measured and has been expressed as a cumulative gas production curves on Figures 2, 3, 4. Gas production curves reflect average value of two identical samples as it was described previously. The 'untreated' term on figures 2, 3 and 4 refers to sludge after digestion without disintegration (a 'raw sludge' term usually being applied for sludge without processing seems to be improper in this specific case).

Figure 1. General arrangement of the testing stand – AER 208 respirometer.

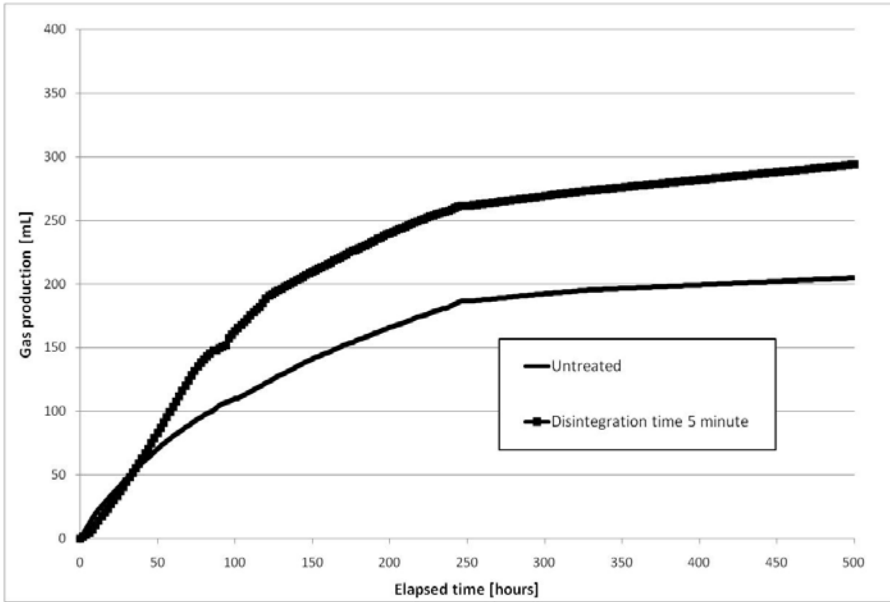

Figure 2. Gas production cumulative curve – time of sonication 5 minutes

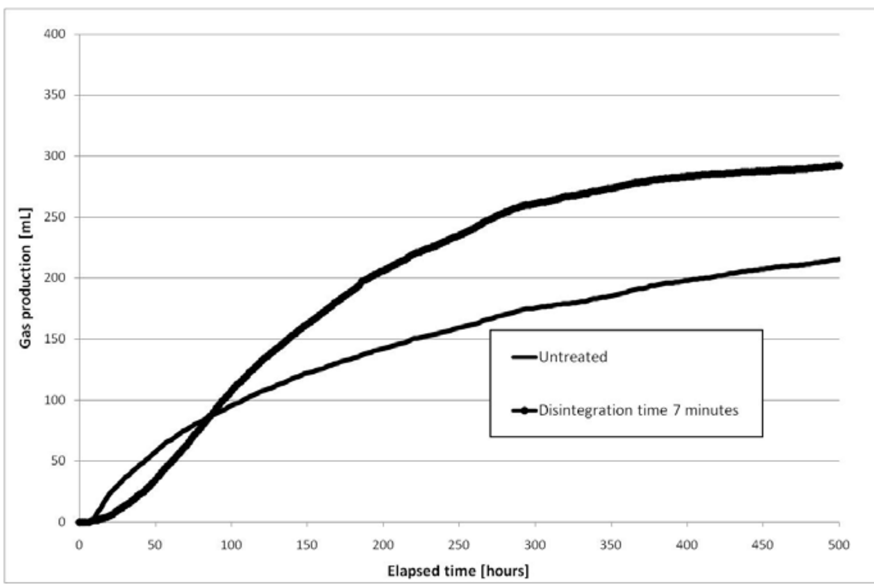

Figure 3. Gas production cumulative curve – time of sonication 7 minutes

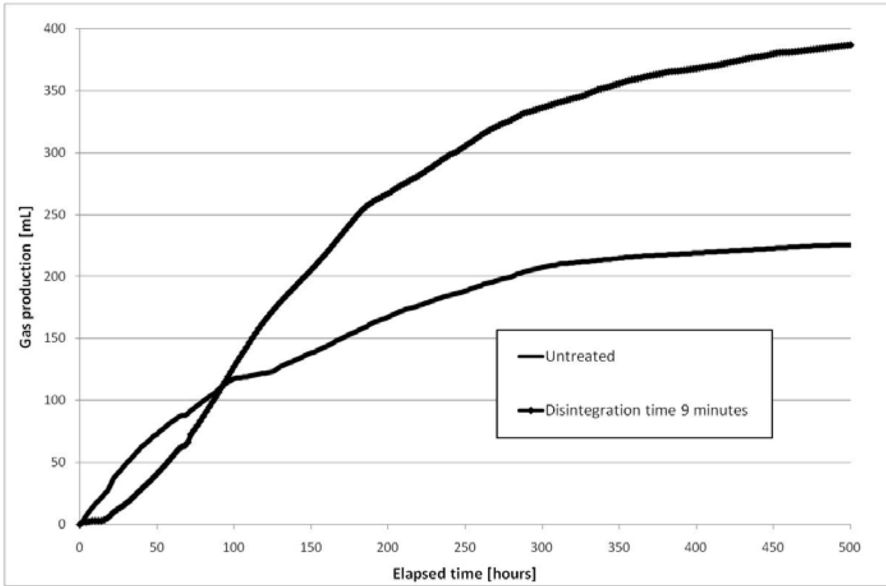

Figure 4. Gas production cumulative curve – time of sonication 9 minutes

Methane content was similar to routine digestion chambers' operation (average 65-70 percent of methane in the fermentation gas). Gas production volumes were completed to compare impact of disintegration and sludge composition on gas production. Tables 1, 2 and 3 summarize results of tests for each of sonication times respectively. Gas production was measured after 500 hours of tests.

Table 1. Respirometric tests' results on sludge disintegration; disintegration time 5 minutes

		Sludge without disintegration			Disintegration time 5 minutes		
		Co	Ce	Change [%]	Co	Ce	Change [%]
Parameters	Units						
COD	mgO_2/l	295	276	7	506	308	64
SS	mg/l	14050	13440	5	12780	12000	7
VSS	mg/l	7500	7450	1	7350	6410	15
Alkalinity	$CaCO_3$	1750	1400	25	1150	1750	(+34)
pH		7,05	7,68	(+8)	7,55	6,97	8
Gas production	ml		372			524	

Where[1] :

Co – value of the parameter in samples before respirometric tests;
Ce – value of the parameter in samples after respirometric tests;
Change [%] – specific change in parameters' values, referred to Co value, value in parenthesis preceded by plus (+) symbol refer to increase of value, otherwise 'change' means decrease.

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[1] Symbols explained in table 1 apply for tables 1 to 3

Table 2. Respirometric tests' results on sludge disintegration; disintegration time 7 minutes

		Sludge without disintegrtion			Disintegration time 7 miutes		
Parameters	Units	Co	Ce	Change [%]	Co	Ce	Change [%]
COD	mgO_2/l	240	218	9	537	270	50
SS	mg/l	9700	9160	6	9640	8770	9
VSS	mg/l	5000	4670	7	5000	4470	11
Alkalinity	$CaCO_3$	1100	1500	(+27)	1050	1650	(+36)
pH		7,53	6,93	8	7,70	6,96	10
Gas production	ml		416			600	

Table 3. Respirometric tests' results on sludge disintegration ; disintegration time 9 minutes

		Sludge without disintegration			Disintegration time 9 minutes		
Parame-ters	Units	Co	Ce	Change [%]	Co	Ce	Change [%]
COD	mgO_2/l	196	186	5	467	186	60
SS	mg/l	9730	9100	6	9540	8600	10
VSS	mg/l	5263	4000	2	5000	4500	10
Alkalinity	$CaCO_3$	1125	1300	(+16)	1075	1680	(+56)
pH		7,60	6,90	9	7,74	6,96	10
Gas production	ml		492			766	

Increase in a fermentation gas production in both series of tests was expectedly bound with decrease in COD concentration, rather then in SS and/or VSS concentration decrease.

Figure 4 shows images of biological preparations of sludge particles (non-dyed on the left and Gram-dyed on the right side). Original structure of sludge flocs is clearly visible. Images of sludge flocs after 7 minutes of ultrasound disintegration shown on Fig. 5, prove significant changes in flock's structure – specific fuzzy look. These structural changes are better observed in dyed samples

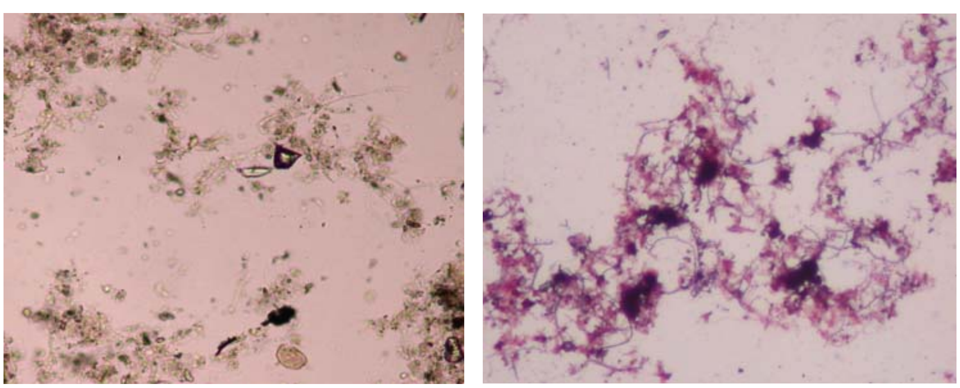

Figure 4. Biological preparations of digested sludge before disintegration (left side non –dyed, right side Gram dyed images).

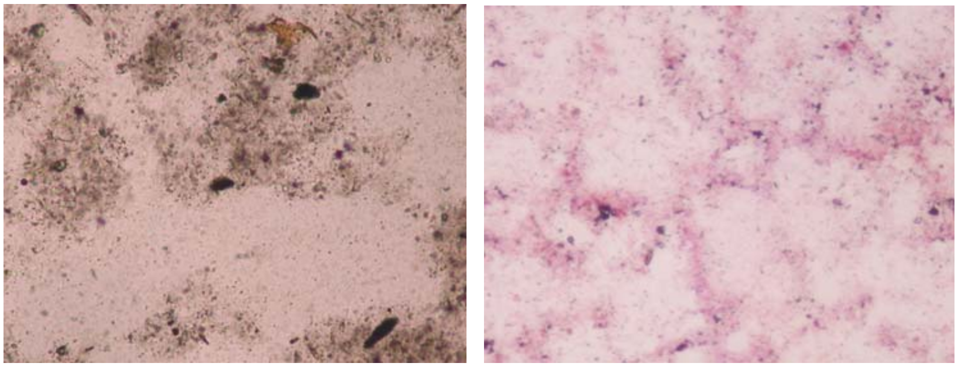

Figure 5. Biological preparations of digested sludge after 7 minutes of ultrasound disintegration (left side non –dyed, right side Gram dyed images).

In both (disintegrated and non-disintegrated) samples a methane-rich gas production from digested sludge was powered by COD consumption rather than by VSS decay. It also confirmed well known role of solubilization in entire process. Please note that production of methane-rich biogas increased with an increase of disintegration time, and also the activity (in simplified form: dynamics of methane production) was growing. This is important information for dimensioning e.g. sludge digestion chambers.

First phase of testing showed possibility of additional yield of a 'biogas' by disintegration followed by additional digestion of previously digested sludge. This observation can be applied in WWTP to improve its overall energetic efficiency. For example passing of some portion of digested sludge through the disintegration installation and addition to the digestion chamber may increase gas production.

The results showing that an increase of the gas production was caused by a longer sonication time were expected and could not be found innovative. But there is other information that may be important for operators and designers:

- Disintegration of digested sludge allows to increase gas production by use of soluble COD released during breaking down cells;
- Sludge digestion followed by disintegration makes it more stable,
- It is possible to rearrange typical full-scale disintegration unit at WWTP to perform dual role: disintegration of WAS prior to digestion and disintegration of digested sludge prior to dewatering; in this case reject waters from digestion are COD rich and its addition back to digestion chamber shall increase overall energetic efficiency.

Direction of further investigation

Further investigations are intended to broaden measurements of changing sonication parameters (intensity and time) for a larger number of plants. These investigations are addressed to prepare a proposition of a protocol for a routine application in the design practice as well as to verify a recovery of microorganisms by feeding extra nutrient (to apply the methanogenic activity tests)

Next stages of the investigations will focus on constituency of soluble phase after disintegration – whether it contain VFAs and should be directed to the plant's head or long-chain fatty acids are dominant which favours digestion chamber as a receiving facility of reject water.

CONCLUSIONS

- Disintegration of sludge may increase recovery of a methane-containing fermentation gas obtained in an anaerobic digestion chamber. Thus it may increase the overall sustainability of wastewater treatment plants.
- Sludge digestion followed by disintegration not only decrease a volume of sludge and its wet mass but also stabilizes it better than other stabilization methods.

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