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EFFECT OF DISINTEGRATION PRETREATMENT OF SEWAGE SLUDGE FOR ENHANCED ANAEROBIC DIGESTION

Renata Tomczak-Wandzel[1], Svetlana Ofverstrom[2], Regimantas Dauknys[3], Krystyna Mędrzycka[4]

[1, 4] *Gdansk University of Technology, Narutowicza str. 11/12, 80-233 Gdansk, Poland.*
[2, 3] *Vilnius Gediminas technical university, Saulėtekio ave. 11, LT-10223 Vilnius, Lithuania.*
E-mails: [1]nata@chem.pg.gda.pl; [2]svetlana.ofverstrom@vgtu.lt; [3]regimantas.dauknys@vgtu.lt; [4]krystyna@chem.pg.gda.pl

Abstract. A sludge disintegration technology, presented in this paper, consists of pretreatment of the sludge before its anaerobic digestion. Disintegration of sludge has been recently incorporated into the wastewater treatment plant's (WWTPs) process scheme in some countries to improve a hydrolysis phase of digestion. Better energy recovery is of crucial importance in the overall sludge disposal. This technology intensifies biogas production and improves the quality of digested sludge. The authors present results of their experiments, performed on sludge samples taken from the Gdańsk WWTP, Poland. During experiments mixture of primary and waste activated sludge (WAS) taken from the aerobic bioreactor was used. The sludge was disintegrated mechanically in a laboratory scale by using a ultrasound generator Hielsher, Germany (the frequency was 24 kHz). The concentration of chemical oxygen demand (COD) was obtained according to standard methods and the degree of sludge disintegration (DD) in supernatant was calculated. The anaerobic digestion experiment was carried out in laboratory scale using two reactors (volume ca. 30 dm^3 of each), with hydraulic retention time (HRT) of 15 days and under mesophilic conditions. The quantity and quality of produced biogas was measured. Results showed 20% increase of biogas and 10% increase of methane produced generated during anaerobic digestion process of disintegrated sludge compare to untreated one.

Keywords: biogas, COD, DD, disintegration, sludge digestion, sludge processing, ultrasound.

1. Introduction

Recently, serious efforts to reduce the volume of sludge requiring treatment and final disposal have been undertaken. The anaerobic digestion process has been extensively studied during the past 20 years and various methods for process improvement have been explored. The investigations concentrated on better sludge hydrolyzation by, for example, thermal pretreatment, chemical solubilization by acid or base addition and mechanical sludge disintegration. During hydrolysis, a substantial fraction of particulates can be separated and decomposed to soluble and less complex forms. Municipal wastewater sludge, particularly waste activated sludge (WAS), is more difficult to digest than primary solids due to a rate-limiting cell lysis step. Physical pretreatment, particularly ultrasonics, is emerging as a popular method for WAS disintegration (Khanal *et al*. 2007, Wei *et al.* 2003, Wang *et al*. 2005, Yoon and Lee 2005, Gronroos *et al.* 2005).

In order to enhance the performance of anaerobic digesters, ultrasound can be used do disintegrate waste activated (WAS) sludge before it is fed to the digester (Neis *et al*. 2008).

This increases the anaerobic digestion efficiency and, as a consequence, increases the volume of biogas produced while at the same time reducing the volume of residual sludge. Another possible use an organic matter obtained from a disintegrated WAS as a source of easy biodegradable carbon for denitrification process. (Müller 2000). The third application is disintegration of filamentous bacteria in the bulked sludge. This method can be a very useful way of sludge bulking or foaming minimization and control (Wünsch *et al.* 1993). The application of disintegration is especially useful for excess sludge because of its high content of micro-organisms (Müller, 2000). Ultrasound of high acoustic intensities causes cavitation in water bodies, if the energy applied exceeds the binding energy of the molecular attractive forces (Suslick 1988). During sound oscillation the local pressure in the aqueous phase falls below the evaporating pressure resulting in the explosive formation of microscopic bubbles. These bubbles oscillate in the sound field over several oscillation periods and grow by a process termed rectified diffusion. The following implosion of the gas and vapour filled bubbles leads to high mechanical shear forces which are apt to disintegrate bacterial cell material. Thus ultrasonic treatment is a suitable method to disintegrate sewage sludge and to overcome the slow biological sludge hydrolysis.

For research, ultrasound have widely been applied as pretreatment of anaerobic digestion; main results of pretreatment of mixture of primary and waste activated sludge are presented in Table 1.

Table 1. Impact of disintegration pretreatment of mixture of primary and WAS

Reference	Treatment conditions	Anaerobic digestion conditions	Results
Tiehm *et al.* 1997	31 kHz, 3.6 kW, 64 s	Continuous, HRT: 22 days, 37°C	Increase of VS removal from 45.8% to 50.3% (+9%)
Wang *et al.* 1999	9 kHz, 200 W, 30 min	Batch, 11 days, 36°C	Increase of CH_4 production from 210 to 345mL/gVS_{in} (64%)
Bien *et al.* 2004	20 kHz, 180 W, 60 s	Batch, 28 days, 36°C	Increase of biogas production (+24%)
Xie *et al.* 2007	20 kHz W/cm^2, 1.5 s	5000 m^3 egg-shape digester HRT: 22.5 days, 29-33°C	Increase of biogas production (+45%)

Source: adapted from Carrère *et al.;* 2010

There are two key mechanisms associated with ultrasonic treatment; cavitation, which is favored at low frequencies, and chemical reactions due to the formation of OH^-, HO_2, H^+ radicals at high frequencies. (Carrère *et al.*; 2010). Ultrasound frequencies range from 20 kHz to 10 MHz. Better sludge disintegration has been reported at a lower frequency range of 20 to 40 kHz (Tiehm *et al.;* 2001, Khanal *et al.* 2007, Carrère *et al.;* 2010).

If one considers that sludge disintegration is carried out mostly to intensify sludge treatment and enhance biogas production during anaerobic digestion, it is very important to evaluate the disintegration degree.

The sludge disintegration process can be described by the particle size analysis. An increase of the energy input leads to a decrease of the floc size (Lehne et al.2001). At the Fig1 and Fig 2 the changes in floc size before and after ultrasound disintegration are presented. Ultrasonic disintegration of activated sludge process resulted more dispersed and homogenous flocks of activated sludge (Cimochowicz-Rybicka *and* Tomczak-Wandzel 2008).

The disintegration degree (DD) of sewage sludge, including bacteria cell lysis, can be evaluated using two methods: analysis of oxygen consumption by bacteria and analysis of organic compounds concentration in supernatant (expressed as COD and protein content) (Lehne et al. 2001).

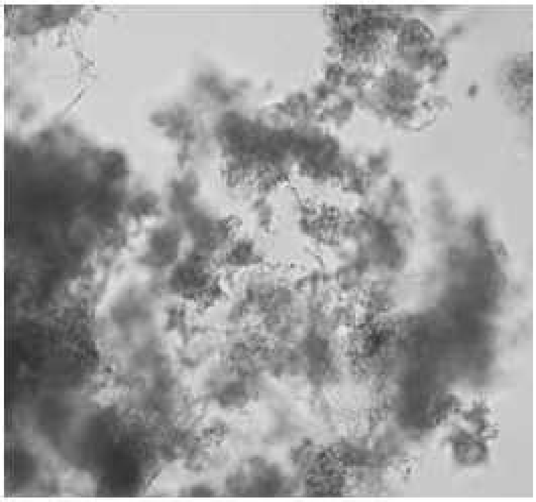

Fig 1. Activated sludge before ultrasonic disintegration

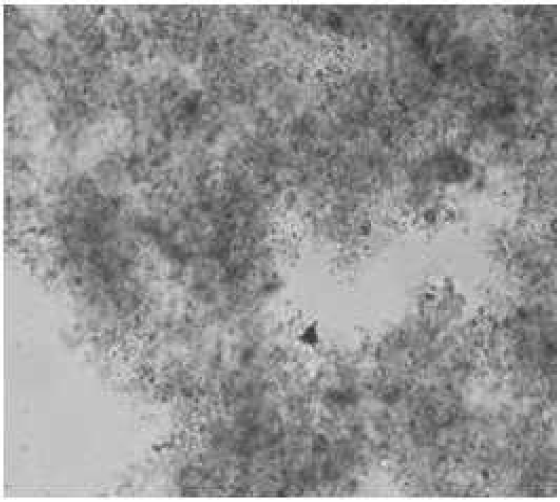

Fig 2. Activated sludge after ultrasonic disintegration

The calculation of energy-consumption and cost shows that disintegration processing of sludge could be realized economically. The excess biogas could be used for electricity generation. The investment for the disintegration equipment has to be seen in relation to the reduced costs for the sludge disposal. However, since 2003-2004 a number of attempts to introduce sludge disintegration have been carried out. An example of a full scale application is the WWTP in Leinetal, Darmstadt-Eberstadt (Germany), Fullinsdorf (Switzerland), Kecskemet and Zalaegerszeg (Hungary), Bamberg (Germany) (Nickel 2005; Eder 2005; Neis *et al.* 2008).

The objective of the study was to examine the modification of mixture of primary and waste activated sludge characteristics due to ultrasonic pretreatment and its effect on the anaerobic digestion process under mesophilic conditions. The effect of this pretreatment was evaluated at lab-scale anaerobic digesters.

2. Materials and methods

Sludge characterization

During this research, mixture of sludge (primary and WAS) was collected from the municipal WWTP Gdańsk WSCHÓD, Poland. This treatment plant serves about 760.000 population equivalents. Such type of sludge is directly fed to the anaerobic digestion. At this WWTP a huge amount of excess sludge is generated and not efficient amount of biogas is produced. Thus, improvement of the sludge treatment efficiency is necessary. One of the options is disintegration of the sludge before its anaerobic digestion.

Utrasound application

The sludge was disintegrated mechanically in laboratory scale by using a 200 W ultrasound generator UP 200S, Hielscher company, Germany (the frequency was 24 kH and the sonification time lasted 5 min).

Examination of sludge disintegration

The DD can be determined by the measuring the specific oxygen consumption OC_d by disintegrated sludge in relation to the specific oxygen consumption OC_0 of the original sludge. The oxygen consumption is directly dependent on the metabolism of aerobic microorganisms. If all bacteria in the sludge are disrupted the oxygen consumption of the sludge is zero and the DD reaches 100% (Kopp *et al.* 1997). Another method of measuring the DD uses COD analysis. Based on this method the organic material released from the cells by their mechanical disruption can be determined. In the current research, the COD content was used for determination of disintegration degree. The selected analytical method is simple and, based on their results, one can learn about the increase in content of easily available substrate for fermentation bacteria in the supernatant.

DD 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 0.5 mol/L sodium hydroxide for 22 hours at 20°C (Müller *et al.*1998, Gonze *et al.*2003, Benabdallah El-Hadj *et al*. 2007).

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

where: COD_d - COD of the centrate of the disintegrated sludge sample, mg/L; COD_i - initial COD of the centrate of the original sludge sample (untreated sample), mg/L; COD_a - the maximum value of COD, which can be obtained in the supernatant after alkaline hydrolysis of the sludge; (chemical disintegration with NaOH), mg/L.

Anaerobic sludge digestion

The anaerobic digestion process was carried out in a semi-laboratory scale. The volume of each of two anaerobic reactors was 30 L (reactor D - sludge after disintegration, reactor R – untreated sludge - reference sample), HRT 15 days. The reactors were used in parallel and were equipped with:

a. Thermal insulation (oil blanket and heater) – to keep the temperature in 37^0 C.
b. Mechanical stirrer – to maintain the good mixing in whole volume of reactor.

The seeding sludge (inoculum) was collected from previous anaerobic digestion test. Same volume (ca. 1 L) of inoculum was added into the both reactors. Reactors were fed once and in parallel. The disintegrated sludge in reactor D was mixed with untreated sludge in ratio 50:50%. This ratio was selected according to proportion of disintegrated and the raw sludge at the real WWTPs with integrated disintegration process.

Analytical procedures

During anaerobic digestion the volume and composition (methane (CH_4), carbon dioxide (CO_2) and hydrogen sulphide (H_2S)) of generated biogas were measured daily by using Gas Analyzers GFM400. The chemical oxygen demand (COD) was determinated according to Polish and EU standard (PN-ISO 6060…). Determination of dry mass was made according to Standard Methods. Samples were dried to constant mass in water bath and than in a thermostatically controlled oven at (105^0C ± 5) with forced air ventilation. Dry mass is expressed in g/kg.

3. Results and discussion

The disintegration degree (DD) of sewage sludge after sonification reached 27%. The disintegration degree (DD) enables an evaluation of the maximum level of sludge solubilization. Increased DD is determined as the substance that can be readily used to produce methane during anaerobic digestion (Wang *et al*. 2005, Erden *and* Filibeli, 2010).

Initially the concentration of COD was completely different due to disintegration process (disintegrated sludge (reactor D) – 2520 mgO_2/dm^3; untreated sludge (rector R) - 530 mgO_2/dm^3). Application of ultrasound disintegration resulted in further destruction of cell walls and increased release of organic matter. During anaerobic digestion COD changed significantly. The highest increase of COD (from 530 to 2590 mgO_2/dm^3) was observed for the untreated sludge. At the beginning the COD of disintegrated sludge increased to 3700 mgO_2/dm^3 on 6th day of the process, than the investigated parameter decreased to 3100 mgO_2/dm^3. In both supernatants the concentration of COD after 15 days of fermentation was still very high.

Fig 3 shows COD content in supernatant obtained from sludge during anaerobic digestion process.

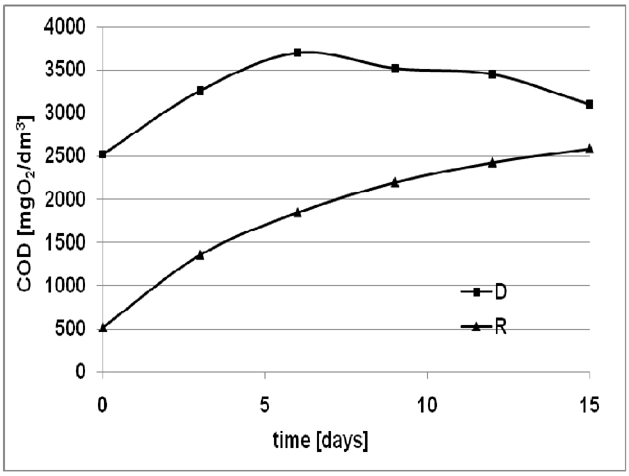

Fig 3. Changes of COD in supernatant during anaerobic anaerobic digestion process (reactor D – sludge after disintegration, reactor R- raw sludge)

The changes of dry mass content during fermentation process are presented in Fig 4.

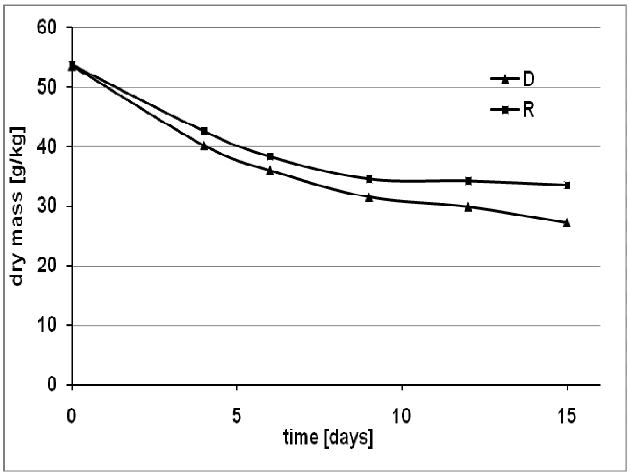

Fig 4. Changes of dry mass content during anaerobic digestion process (reactor D – sludge after disintegration, reactor R- raw sludge)

The decreasing of dry mass is a result of decomposition of organic substances during fermentation process and is an effect of biogas production. The course of decomposing organic matter in both sludges was quite similar. However, finally after 15 days of the anaerobic process the decreasing of dry mass in disintegrated sludge ranged 49.3%. In untreated sludge reduction of dry mass was in lesser degree – only 37.7%. At the end the difference between investigated sludges was about 12%. It is significant amount of residual sludge which still remain after anaerobic digestion to the final utilization.

The volume of biogas during 15 days of anaerobic digestion process is presented in Fig 5. The bigesst amount of biogas in both reactors was produced in a few first days of anaerobic digestion. The biogas was more intensively generated in reactor with disintegrated sludge due to high content of easy biodegradable substances after sonification (COD was visibly highest). The total volume of generated biogas from desintegrated sludge was 20% (78 dm^3) higher than from untreated sludge (60 dm^3). The volume of produced biogas after 15 days of experiment was very low in both reactors and analyses were stopped.

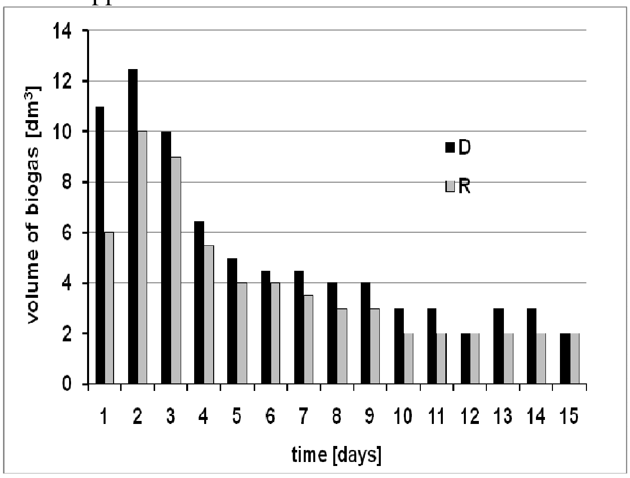

Fig 5. The volume of biogas generated during anaerobic digestion process (reactor D – sludge after disintegration, reactor R- raw sludge)

The change of the methane content in biogas is presented in Fig 6. The analysis of biogas composition shows that the obtained volume of methane from disintegrated sludge was higher during the total time of examination.

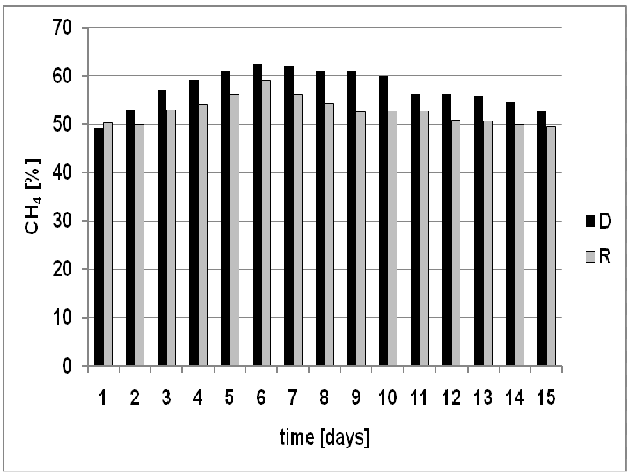

Fig 6. The volume of methane generated during anaerobic digestion process (reactor D – sludge after disintegration, reactor R- raw sludge)

The maximum content of methane was 62.4% in the reactor with sludge after sonification, and in untreated sludge the maximum content range 59.1%. In both chambers this value was obtained after six days of anaerobic digestion. Totally the volume of methane produced from disintegrated sludge was about 10% higher than in untreated sludge. It is very important from the economic point of view. It providing higher biogas yields and hence increased power generation from biogas. The content of carbon dioxide (CO_2) from disintegrated sludge was lower (34.0-43.3%) than from untreated sludge 35-46%).

Concentration of hydrogen sulphide (H_2S) was similar in both reactors and ranged from 2300 to 2900 ppm.

4. Conclusions

Disintegration of sludge will be an area with major perspectives in the field of sewage sludge treatment. The disintegration of sewage sludge by sonification destroys the flocks' structure of sludge and disrupts the cell walls of the micro-organisms. Due to sludge disintegration, organic compounds were transferred from the sludge solids into the aqueous phase resulting in an enhanced biodegradability. Our experiments have demonstrated that ultrasound sludge disintegration could positively affect sludge anaerobic digestion.

The advantages resulting from ultrasound disintegration of the sludge can be listed as follows:

- increase of sludge digestion efficiency;
- increase about 20% the volume of biogas produced;
- increase about 10% the methane content in biogas;
- reduces the volume of residual sludge (12%).

Therefore disintegration of sewage sludge is a promising method to enhance anaerobic digestion rates and lead to reduce the volume of sludge digesters and the time of process.

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