THE USE OF ULTRASOUND TO ACCELERATE THE ANAEROBIC DIGESTION OF WASTE ACTIVATED SLUDGE

Ewa Neczaj, Joanna Lach

Technical University of Czestochowa, Institute of Environmental Engineering,
BrzeŸnicka 60a, 42-200 Czêstochowa, Poland,
Phone: 0048343250917, Fax. 0048343721304, e-mail: iis@is.pcz.czest.pl

Abstract

Anaerobic fermentation is most commonly applied process for stabilization of sewage sludge. Anaerobic digestion technologies have traditionally been employed to reduce of volume and weight of sludge and produce corresponding amount of biogas. The slow degradation rate of waste activated sludge in anaerobic digester is due to the rate limiting step of sludge hydrolysis. This is caused by a low biodegradability of the cell walls and extracellular biopolymers formed in activated sludge.

The methods of improvement of the biodegradability of particular substrate are mainly based on better accessibility of the substrate for microorganisms. In this study the effect of ultrasound pretreatment on sludge degradability was investigated using ultrasound at a frequency of 20 kHz and high acoustic intensities. Ultrasound treatment resulted in waste sludge disintegration as was demonstrated by increase of Chemical Oxygen Demand in sludge supernatant and size reduction of sludge solids.

The fermentation experiments were performed in a laboratory plant consisting of two stirred tank fermenters which were operated in parallel at 35 ^{o}C. As a control one anaerobic fermenter was operated with untreated waste sludge.

The results show a significant improvement of the removal rates of substrates and the enhancement of methane production in fermenter operated with the sludge disintegrated by ultrasounds.

Introduction

Waste water treatment processes are closely interlinked with sludge production and consequently with sludge treatment for both municipal and industrial wastes. Anaerobic fermentation is most commonly applied process for stabilization of sewage sludge (1). The process of anaerobic digestion is accomplished through four steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis. Anaerobic digestion technologies have traditionally been employed to reduce of volume and weight of sludge and produce corresponding amount of biogas. The end product is digested sludge which still contains about 50 % volatile solid. The organic fraction of excess activated sludge is only about 30-45 % digestible in conventional anaerobic treatment (2,3). The slow degradation rate of sludge in anaerobic digester is due to the rate limiting step of sludge hydrolysis (the hydrolysis of particular organic matter to soluble substances) (4). This is caused by a low biodegradability of the cell walls and extracellular biopolymers formed in sludge because the solid phase of waste activated sludge is mainly composed of particulate organic material (microorganisms).

In the European Union, digested sludge is due to be banned from landfill sites because of its high organic content. Therefore it is important firstly to reduce the amount of sludge produced and secondly to reduce its residual organic content.

The methods of improvement of the biodegradability of particular substrate are mainly based on better accessibility of the substrate for microorganisms. Pretreatment of sewage sludge by mechanical, chemical, or thermal disintegration can improve the subsequent anaerobic digestion.

The attention of researches, technology designer and manufactures of relevant equipment has been focused on ultrasonic disintegration (5). Although there have already been introduced some technical installations taking advantage of active reaction of ultrasonic field for the preparation of sludge prior to anaerobic stabilization, yet in view of mechanisms of the process and methods to control the run of the process, the technology in question is still in the experimental phase.

The impact of ultrasound waves on liquid causes the periodical compression and rarefaction of the medium. Cavitation occurs above a certain intensity threshold, when gas bubbles are created which

first grow in size before violently collapsing within a few microseconds. The violent collapse produces very powerful hydromechanical shear forces in the bulk liquid surrounding the bubble. Cavitation is accomplished by high pressure gradients and extreme increase of the temperature inside the bubble. These extreme conditions can lead to the thermal destruction of compounds present in the cavitation bubbles and to the generation of very reactive hydroxyl radicals. The effects that can be observed when cavitation is generated in aqueous solution can be summarized as:

- High mechanical shear stress
- Radical reactions: creation of OH and H radicals; chemical transformation of substances
- Thermal breakdown of volatile substances

In this study the effect of ultrasound pretreatment on sludge degradability was investigated using ultrasound at a frequency of 20 kHz and high acoustic intensities. The aim of the research was to examine the effect of sludge disintegration on the anaerobic sludge stabilization process.

Methods

The experiments were done with waste activated sludge (WAS) obtained from the municipal full-scale treatment plant of Czestochowa. The WAS prior to passing it to fermentation process, was subjected to ultrasonic disintegration. The disintegration of sludge was carried out in static conditions using disintegrator UD 20. The field of 20 kHz was used for sonification and the sonification time was varied from 60 to 420 s.

A mesophilic single stage-anaerobic digestion was studied by using two 5 l completely stirred glass digester, placed in a temperature controlled chamber at 35^{o}C. The first reactor was fed disintegrated waste activated sludge. As a control one, the second anaerobic fermenter was operated with untreated sludge. Both reactors were seeded initially with digested sludge from the mesophilic anaerobic digester from the same treatment plant. The produced biogas was collected in calibrated glass cylinders. The cylinders were filled with acidified aqua deion. to avoid losses of CO_2 due to formation of carbonate. Standards methods were used for measurement of COD and total solids (TS), volatile solids (VS), volatile fatty acids (VFA) and pH. The percentage of methane and carbon dioxide were analyzed by a gas chromatograph (Shimadzu).

For the analysis of aqueous phase supernatants (COD and VFA concentration), the particulate sludge material was removed by centrifugation followed by filtration through 0.45 μm pore size cellulosenitrate membrane filters.

Results

In the first step of investigation the optimal time of sonication was determined. Figure 1 shows release of dissolved organic substances into the aqueous phase after ultrasonic treatment of waste activated sludge.

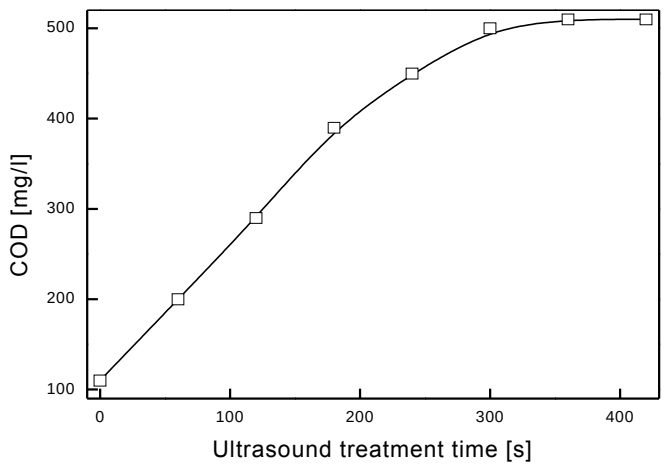

Figure1. Increase of COD in the sludge supernatant after ultrasound treatment of waste activated sludge.

It was found that with increasing sonication time the concentration of organic substances in liquid phase increased significantly. The dissolved organic substances are represented by the parameter chemical oxygen demand (COD). It seems that after 300 s the curve starts to level out suggesting that disintegrating action on the microorganism cells cannot be driven further. At this point the concentration of dissolved organic matter was already raised from 110 mg/l to 500 mg/l. Hence the exposition time of 300 s was defined as an optimal sonication time.
In the next step of these experiments, the anaerobic digestion of waste activated sludge following ultrasonic pretreatment was studied. In batch experiments, the degradation kinetics of untreated and ultrasound treated sludge was determined in the fermenters operated with identical detention time of 8 days. The results of studies were presented in Tables 1 and 2.

Table 1. The experiment with ultrasound treated WAS

Day of process	pH	Alkalinity* [mg/l]	VFA* [mg/l]	VF [g/l]	TS [g/l]	COD* [mg/l]
Before digestion	7.2	720	97.7	5.3	8.2	560
1	6.6	1030	627.6	4.8	7.7	850
2	6.9	960	680.0	3.4	6.5	1400
3	6.9	825	820.0	3.4	6.4	1450
4	6.9	790	840.6	3.4	6.4	1290
5	6.9	680	865.8	3.4	6.3	1380
6	6.8	655	880.5	3.2	6.3	1430
7	6.8	630	950.8	3.1	6.3	1420
8	6.7	610	1036.7	2.9	6.2	1410

* - parameters measured in the liquid phase above the sludge

Table 2. The experiment with untreated WAS

Day of process	pH	Alkalinity* [mg/l]	VFA* [mg/l]	VF [g/l]	TS [g/l]	COD* [mg/l]
Before digestion	7.2	720	97.7	5.3	8.2	120
1	7.1	1030	127.6	5.1	8.1	125
2	7.0	1000	130.0	4.9	8.1	130
3	7.0	950	190.0	4.8	8.0	150
4	6.9	940	210.6	4.8	8.0	179
5	6.8	880	225.0	4.6	7.9	132
6	6.7	725	250.5	4.5	7.8	150
7	6.6	630	280.0	4.3	7.7	170
8	6.3	580	319.6	4.2	7.7	187

* - parameters measured in the liquid phase above the sludge

Remarkably volatile solids in the effluent of the digester fed with disintegrated sludge were 31 % less than in the conventional process. In the fermenter operated with disintegrated WAS the concentration of volatile fatty acids (VFA) was very high and increased from 627 mg/l to above 1000 mg/l. In the second reactor, the control one, VFAs increased from 127.6 mg/l to 319.6 ml/l.
The concentration of COD in the liquid phase above the sludge during digestion of ultrasound treated WAS was several time higher then in the control reactor.
Anaerobic digestion was significantly improved by ultrasound pretreatment of waste activated sludge. The reduction of volatile solids decreased slightly to 45 % as compared to 21 % obtained with conventional anaerobic digestion with the same residence time. Obviously the organic compounds transferred by ultrasound from the sludge solids into the aqueous phase are readily biodegradable.
Significantly higher amounts of biogas were produced in fermenter fed with disintegrated sludge (figure 2). The biogas consisted of in all fermenters of 2/3 CH_4 and 1/3 CO_2.
Table 3 summarizes the results obtained during digestion process. The VS reduction of the control

fermenter was 20.8 %. It was 45.2 % in the fermenter operated with the sludge that was sonicated for 300 s.

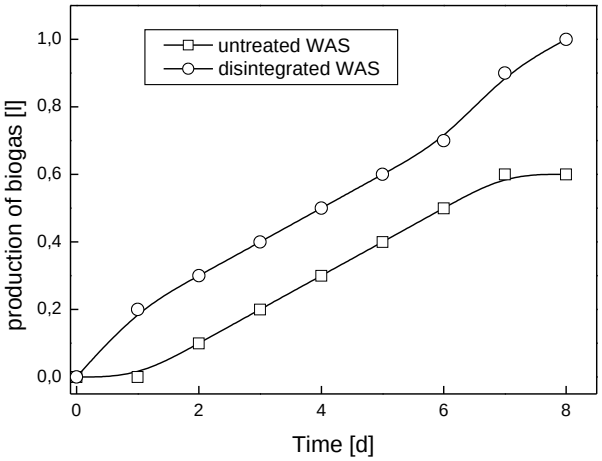

Figure 2. Production of biogas during fermentation of untreated and ultrasound-treated waste activated sludge.

Table 3. Effect of ultrasound treatment on waste activated sludge digestion.

	Control	Disintegrated WAS
Volatile solid degraded (%)	20.8	45.2
Gas production		
Total biogas (l)	2.6	4.8
Biogas/ VS degraded (l kg^{-1})	182	400
CH_4 (%)	63.2	67.8
CH_4/VS degrade (l kg^{-1})	320	275

Discussion

In conventional anaerobic treatment the biological hydrolysis is the rate limiting step. Thus, the efficiency of anaerobic digestion can be greatly enhanced by improving the rate of the sludge hydrolysis using ultrasound (6). The presented results of our research showed that pretreatment of waste activated sludge by ultrasonic disintegration has positive impact on anaerobic sludge stabilization.

Ultrasound treatment of WAS caused a transfer of organic substances from the sludge solids into the aqueous phase. The effect of disintegration expressed by increase of COD concentration in sludge liquid subjected to sonication depends on ultrasound treatment time. The concentration of COD, which is representing dissolved organic substances, was increasing with the increase of disintegration time, and the highest increase was observed with the disintegration time change from 60 to 300 s. After that point the curve started to level out (figure 1).

The disintegration pretreatment resulted in a better anaerobic degradation of WAS. The effect of disintegration was the increase of COD and VFA concentration in liquid phase (Tables 1 and 2). It is generally known that in the closed anaerobic reactor, in which the organic substance degraded by microorganisms is the only source of organic carbon, the basic source of easily assimilated organic carbon is made by short-chain carboxylic acids. According to McCarty 72 % of the organic substance defined as COD is disintegrated to acetic acid, from which, due to decarboxilation, methane and CO_2 are formed, which in turn are the main components of biogas being the products of methanogenesis. The obtained results show significantly generation of VFAs in the reactor fed with disintegrated sludge (VFA concentration increased ten times). Faster generation of VFAs caused faster biogas

production. In that cause the total biogas production was almost two times higher comparing with the control fermenter. Although the total volume of produced biogas was higher the specific biogas production i.e. the biogas production related to mass of VF degraded, was lower for the disintegrated WAS as compared to the control. This effect might be due to changes in the biochemical fermentation process (7).

Conclusion

In this study, ultrasonic disintegration of waste activated sludge was examined in order to improve the anaerobic stabilization process. The most important results are:

- Ultrasonic pretreatment enhances the subsequent anaerobic digestion resulting in a better degradation of volatile solids and increased production of biogas
- Volatile solids concentration in the effluent of the digester fed with disintegrated sludge were 31 % less than in the conventional process
- Total biogas production was almost two time higher for disintegrated waste activated sludge

References

1. J.F. Malina, F.G.Pohland, “Design of anaerobic process for the treatment of industrial and municipal wastes”, Water quality management library, vol. 7, Technomic Publishing Company, Lancaster, USA, (1992)

2. S. Tasuo, K. Kudo, Y. Nasu, Anaerobic waste activated sludge digestion – a bioconversion mechanizm and kineic model, Biotech. Bioeng., **41**, 1082-1091, (1993)

3. S.T.L. Harrison, Bacterial cell disruption; a key unit operation in the recovery of intracellular products, Biotechnol. Adv. **9**, 217-240, (1991)

4. J.A. Estman, J.F. Ferguson, Solubilization of particulate organic carbon during the acid phase of anaerobic digestion, J.Water Pollut. Control Fed, **53**, 352-366, (1981)

5. A. Tiehm, K. Nickel, M. Zellhorn,U. Neis, Ultrasonic waste activated sludge disintegration from improving anaerobic stabilization, Wat. Res.,**35(8),** 2003-2009, (2001)

6. J. Mueller., G. Lehne, J. Schwedes, S. Battenberg, R. Näveke, J. Kopp, N. Diechtl, A. Scheminski, R. Krull, D.C. Hempel, Disintegration of sewage sludges and influence on anaerobic digestion, Water Sci. Technol. **38(9)**, 425-433, (1998)

7. A. Tiehm, K. Nickel, U. Neis, The use of ultrasound to accelerate the anaerobic digestion of sewage sludge, Water Sci. Technol., **36(11),** 121-128, (1997)