Sonication of sludge by innovative high-power ultrasound technology – Practical Experiences

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ABSTRACT

Biological cell lysis is known to be the rate-limiting step of anaerobic biosolids degradation. Due to the slow pace by which this reaction occurs, it is necessary to equip wastewater treatment plants with large digesters or alternatively incorporate technological aids. High-power ultrasound used to disintegrate bacterial cells has been utilized as a pre-treatment process prior to anaerobic digestion. Through this application, as seen on pilot and full-scales, it is possible to attain up to 30% more biogas, an increase in VS-destruction of up to 30% and a reduced sludge mass for disposal. Utilizing ultrasound technology in aerobic applications is a new and innovative approach. Improved denitrification through a more readily available internal carbon source and less excess sludge mass can be traced to the positive effects that sonication of sludge has on the overall biological wastewater treatment process. Reference full-scale installations suggest that the technology is both technically feasible and economically sound.

1. INTRODUCTION

The stabilization of biosolids produced in most wastewater treatment plants is done by anaerobic digestion. Worldwide, it is the preferred method used for sludge stabilization primarily because the process provides three very appealing benefits: 1) biogas is the end product attained in the anaerobic food chain, 2) further handling is made possible, especially dewatering, and 3) the sludge volume for disposal is reduced [1]. With the ever-increasing amount of people that are becoming connected to sewer treatment plants, the optimization of and continuous attempts to improve the anaerobic digestion process are essential [2].

Should one instead choose to view the process of biological wastewater treatment that operates under aerobic conditions, the activated sludge process lies in focus. The bio-availability of the organic components is decisive in the efficiency of the overall process and specifically denitrification. Regarding the activated sludge process, operators are also faced with challenges such as combating bulking and foaming sludge. These situations have proven to be reoccurring problems for plants located in temperate climate zones.

There are several available techniques on the market today, which can be employed in order to achieve improved anaerobic and aerobic digestion on wastewater treatment plants. Great interest has been devoted to ultrasound and the effects that the application has on sludge. Investigations in the field originated over a decade ago and since then advancements have been made both in the area of research and full-scale applications. It has been proven that low-frequency ultrasound (below 100 kHz) generates the cavitation necessary to produce the mechanical shear forces associated with sludge disintegration [3]. Combined with ultrasound of high-intensity, 25-50 W/cm^2 [3], the cells are actually destroyed and the intracellular material is released into the medium [4].

2. METHODS - ENHANCING ANAEROBIC DIGESTION

Controlled Conditions

In order to enhance the performance of anaerobic digesters ultrasound can be used to disintegrate waste activated sludge (WAS) before it is fed to the digester. Using high-power ultrasound for disintegration by cavitation is a relatively new application in sewage sludge treatment [3,4]. The bacterial cells in the sludge break apart and are subsequently destroyed, as the effects of mechanical cavitation are so powerful that microbial cell walls are broken when the cavitation bubbles implode. The contents of the cell are then released into the medium, resulting in a higher degree of substrate bio-availability for the remaining living microorganisms. In effect, enzymatic-biological hydrolysis, which is the initial and rate-limiting step of the anaerobic food chain, is substituted and catalysed by this mechanical disintegration of the sludge [5].

Earlier pilot studies (1998-2000) on the fermentation of waste activated sludge (WAS) have been conducted, upon which we would like to report again briefly in order to set the scene [4]. Five 200-liter digesters were operated at 37ºC in parallel. The test reactors were fed sonicated WAS from the Bad Bramstedt WWTP, Germany, and the control reactors received untreated sludge. Ultrasound treatment for 90 seconds at an intensity of 8 W/cm^2 and a frequency of 31 kHz was applied. The hydraulic retention time was varied between 4 and 16 days. The degree of cell disintegration (DD_{COD}) according to eq. (1) was determined in the supernatant of the centrifuged sludge samples as well as a number of standard parameters [4].

$$DD_{COD} = [(COD_{Ultrasound} - COD_0) \ / \ (COD_{NaOH} - COD_0)] * 100 \quad [\%] \qquad (1)$$

where $COD_{Ultrasound}$ is the chemical oxygen demand of the disintegrated sample (here by sonication), [mg/l],

COD_0 is the chemical oxygen demand of the untreated sample, [mg/l],

COD_{NaOH} is the chemical oxygen demand of a reference sample hydrolysed chemically in a 0.5 molar NaOH solution at 20°C for 22 hours, [mg/l].

Table 1: Effects of ultrasound pre-treatment (at 31 kHz) and subsequent digestion time on anaerobic volatile solids degradation (VS_{deg}) of waste activated sludge and biogas production. Results obtained from long-term pilot scale studies using 200-liter digesters operating at 37ºC with variable retention times. Only one fermenter (sonicated sludge) available with 4 d HRT.

WAS	HRT [d]	Degradation rate [g VS_{deg}/(m^3 digester volume*d)]	Degree of degradation [%]	Biogas production rate [m^3/ m^3 digester volume*d)]
Untreated	16	257	32.3	0.19
Disintegrated	16	335	42.4	0.21
Untreated	8	430	27.0	0.31
Disintegrated	8	603	38.1	0.36
Disintegrated	4	1011	32.0	0.52

The DD_{COD}, gas production and VS-degradation in the digesters fed with ultrasonically treated sludge, all exhibited higher values as compared to the digesters fed with untreated sludge (Table 1). The VS-degradation rate of the sonicated biosolids at HRT=16 days increased by more than 30% as compared to conventional digestion at the same retention time. The effects are even more pronounced in the digesters that operated at a retention time of 8 days. Comparing the degree of degradation for this pair of reactors, an improvement in degradation of more than 40% is noted. The highest rate of VS-destruction, however, was observed in the digester operating at the shortest HRT (4 days). The volumetric degradation rate of the digester operating at a four day retention time increased nearly by a factor of four, as compared to the conventional digester operating at a HRT of 16 days (1011:257). The most significant biogas production in relation to the digester's volume can be seen in the digester that was operated at a HRT of 4 days. All digesters fed with ultrasonically treated sludge, however, displayed an increased biogas production when compared to their conventional digester counterparts.

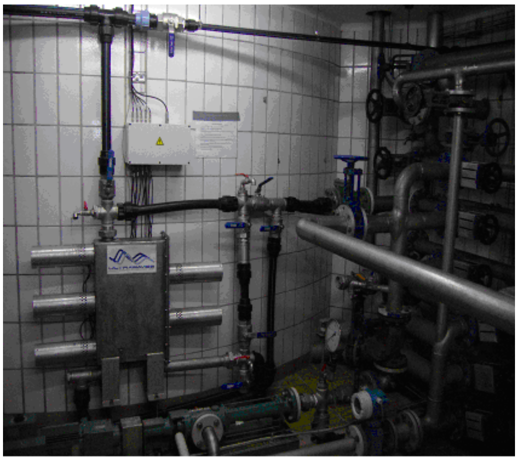
It is apparent that the anaerobic digestion process is significantly accelerated by the use of ultrasonic pre-treatment. The pilot studies conducted with the 200-liter digesters have provided the significant results needed in order to knowledgably and effectively handle challenges that arise on full-scale installation venues.

Full-Scale Conditions

Meldorf WWTP, Germany

A full-scale installation was implemented at Meldorf WWTP (65,000 PE) in February 2005 after a three-month test period. The plant was experiencing problems with foaming in the anaerobic digester as a result of excessive growth of filamentous bacteria (*Microthrix parvicella*) in the waste activated sludge. The purpose of the ultrasound installation was to eliminate the source of the foaming problems and thereby ensuring an undisturbed anaerobic digestion. Sonication was applied to 100 % of the thickened waste activated sludge (TWAS) flow before it was led to the two anaerobic digester tanks present at the plant.

A short time after the installation of the ultrasound equipment at the Meldorf WWTP, the problems with foaming sludge were no longer an issue. This, in turn, provided the conditions necessary for a smooth and effective digestion of the sludge when it reached the fermenter.



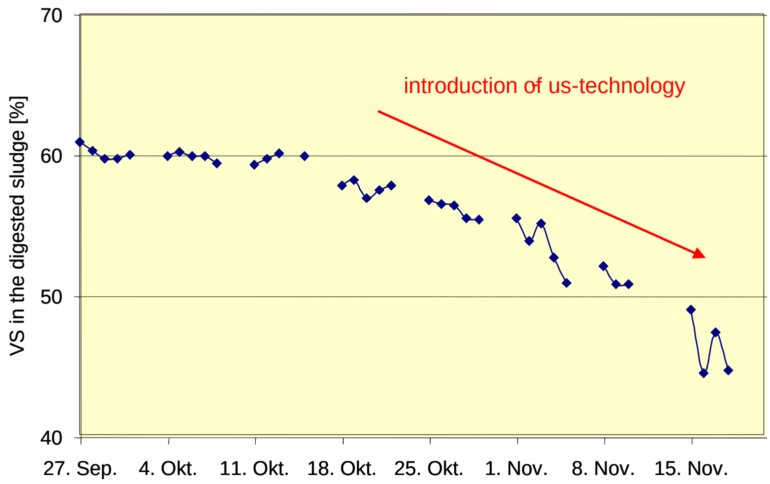


Figure 1: Installation at Meldorf WWTP and results. The volatile solids (VS) in the digested sludge were significantly reduced in conjunction with the introduction of ultrasound technology at Meldorf WWTP. Analyses reveal that the VS content of the digested sludge was reduced from 60% to 45% over the course of the test period.

The VS, expressed as percent of dry solids, were reduced from 60% to 45% in the stabilized sludge (Figure 1). With regard to biogas production, a 30% increase after the ultrasound installation was noted as compared to before the installation. These improvements correspond to improved self-sufficiency with regard to energy supply and a reduced sludge mass for disposal. In addition, the feeding of co-substrates was made possible as a result of the improved stability of the anaerobic digestion process. The plant was able to accept process liquids from a local food producer, which serves the interests of both parties.

Bamberg WWTP, Germany

On target for intensifying the anaerobic sludge stabilization, the ULTRAWAVES ultrasound technology has been installed at Bamberg WWTP (design capacity 220,000 PE). Caused by the improvement and the increase of the collection system the wastewater load in Bamberg has been raised to ca. 330,000 PE. More sludge was produced and the total retention time in the three existing digesters was decreased to less than 20 days. At first the problem should have been solved by building a new digester. After a successful test phase, the technical management decided to install two ULTRAWAVES ultrasound systems (each with a power consumption of 5 kW). This way the construction of a new digester was avoided and an enormous financial expense of ca. 1.5 mio. € was saved.

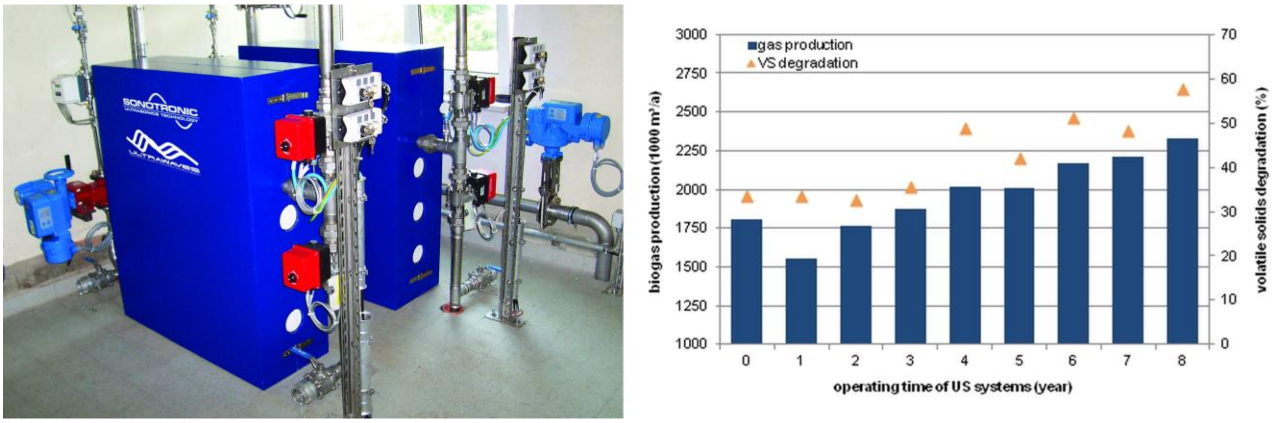


Figure 2: Installation at Bamberg WWTP and results. By using the ULTRAWAVES ultrasound systems the degradation of the organic sewage sludge components was increased from 34% at the beginning to more than 50%. At the same time the biogas production was increased by more than 30%.

By using the ULTRAWAVES ultrasound systems the degradation of the organic sewage sludge components was increased from 34% at the beginning to 58% (Figure 2). At the same time the biogas production was increased by more than 30%. In this regard long-term effects of excess sludge sonication can be verified. In October 2010 new gas engines with a better electrical efficiency were installed at the WWTP. Nowadays at Bamberg WWTP more electrical power is produced from the anaerobic digestion of the sludge than it is necessary for the wastewater treatment. Hence, the Bamberg WWTP is the first European energy-sufficient WWTP in this range (without co-substrates, sewage sludge is the only energy source for the anaerobic digestion process) in Europe.

Shek Wu Hui STW, Hong Kong

For a current demo test one ULTRAWAVES ultrasound reactor unit has been installed on Shek Wu Hui STW (300,000 PE) in Hong Kong since April 2014. Conventional sludge stabilization on SWH STW is done in four existing anaerobic digester tanks at a total hydraulic retention time of about 21 days. The demo test is performed over a six months period and performance evaluation is done on mass balance calculations. Therefore DSD technical staff is collecting daily data regarding volatile solids load in the feed sludge (thickened primary sludge and thickened surplus activated sludge) and in the digested sludge. Although the load of organic sludge matter to the anaerobic digesters has not significantly changed we can identify a trend of increased biogas production (Figure 3).

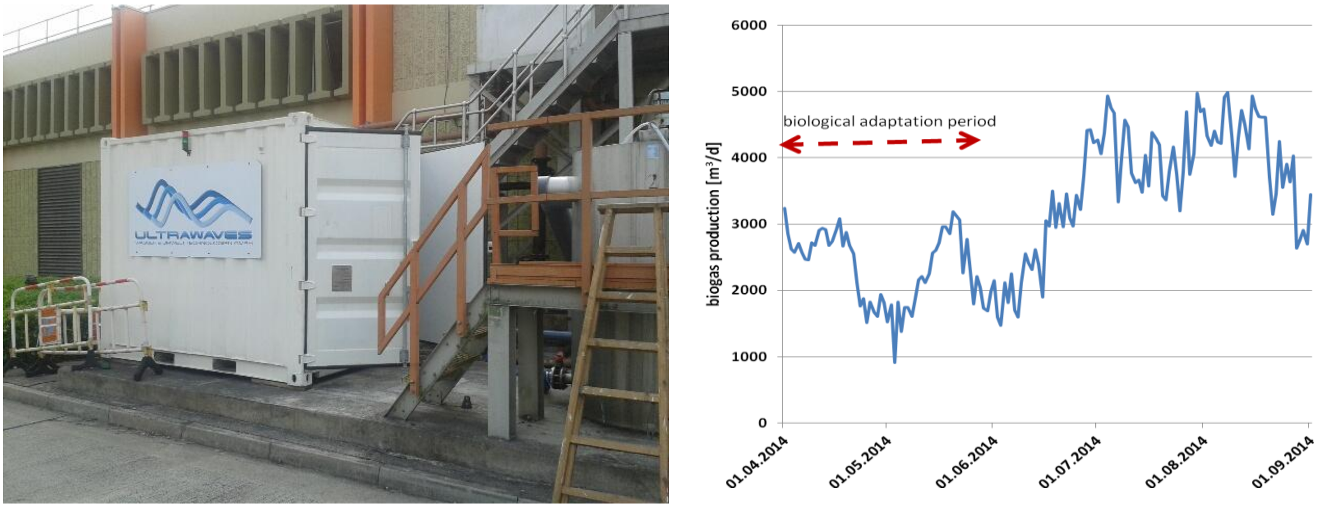


Figure 3: Demo Installation at Shek Wu Hui STW. A 5 kW ULTRAWAVES ultrasound reactor unit as plug&play system in a 10´-conatiner is operating since April 2014. After the typical adaptation period we can observe an increase in biogas production.

3. METHODS - ENHANCING AEROBIC DIGESTION

In order to enhance the aerobic digestion process, sonicating activated sludge before returning it to the activated sludge tank (as return activated sludge) has emerged as a new and innovative approach to intensify denitrification [6]. We are following this approach, which entails providing an internal carbon source in order to enhance the efficiency of denitrification. Though the mechanisms governing the reactions that ultimately result in this improvement are not fully known or understood, research in the field of ultrasonically treated sludge to improve anaerobic digestion provides valuable leads.

Upon sonication, the microorganisms in the sludge become stressed and the colonies break apart. Filamentous colonies are destroyed by the powerful shear forces created by the implosion of cavitation bubbles, reducing or completely eliminating the negative effects associated with their presence. In addition, it is believed that the biological processes that proceed in the sludge are stimulated by the release of intercellular material from the destroyed cell. Specifically, released enzymes are thought to play a significant role in stimulating various biological processes. The destroyed cellular material itself serves as a non-foreign carbon source for the remaining viable microorganisms in the sludge. In this way we are able to reach an intensified denitrification.

Full-Scale Conditions

Bünde WWTP, Germany

A full-scale installation has been in place at the Bünde WWTP (actual load 54,000 PE) since September 2006. A test period of four months had, by this point, been successfully completed and the decision to proceed with the installation was based on the convincing results obtained during the test period. The nitrogen elimination at the plant occurs via intermittent denitrification. The reason for implementing the ultrasound technology on the plant was that denitrification efficiency was suffering as a result of insufficient carbon source for the denitrifying bacteria. Using sonicated thickened waste activated sludge as an internal carbon source to improve denitrification was seen as a viable option. In total 30% of the TWAS stream was sonicated and led back to the activated sludge tank, providing the process with the carbon source needed for elevated denitrification efficiency.

After sonication ceased in July 2006, the concentrations again climbed to the pre-sonication levels seen in 2005. Sonicating a partial stream of the thickened waste activated sludge before leading it back to the activated sludge tank provided the carbon source necessary to facilitate the improvement in denitrification.

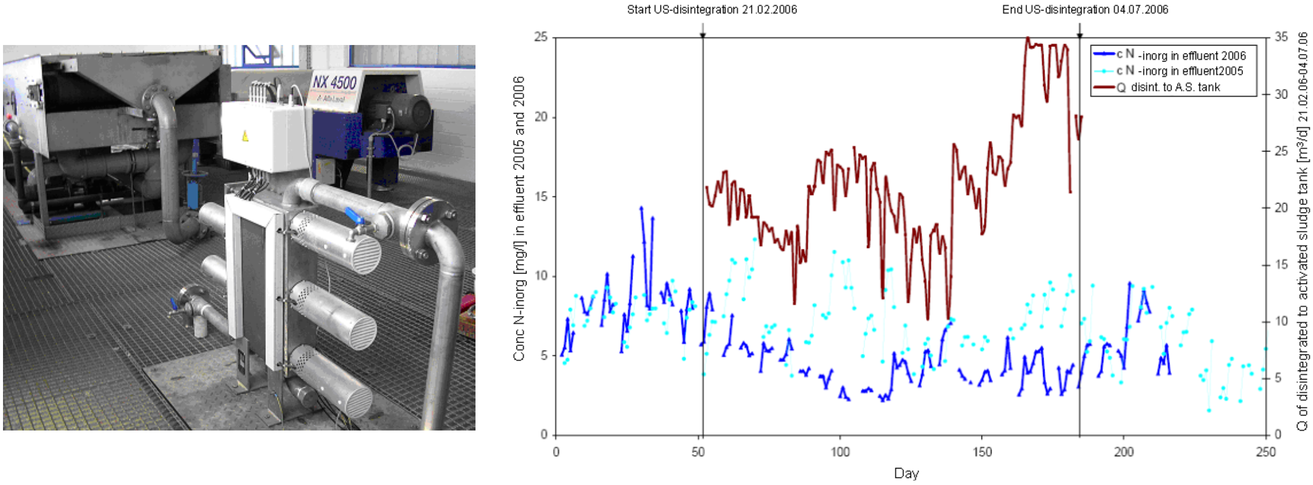


Figure 4: Installation at Bünde WWTP and results. The lower N-inorganic concentration in the effluent of Bünde WWTP during the sonication period in 2006 corresponds to a higher degree of efficiency with regard to denitrification.

Utilizing sonicated TWAS as an internal carbon source for the purpose of improving denitrification yielded several positive effects. First, a significant reduction of nitrogen in circulation at the plant was achieved, which means that denitrification had been improved (Figure 4). In addition, there were several secondary effects that contributed to an overall efficiency of the plant operations. Excess sludge was reduced by 25% and the dewaterability of the sludge was improved by 2%. A reduction of the organic fractions present in the sludge was attained and foaming and bulking sludge in the activated sludge tank was virtually eliminated.

It is apparent that several positive advantages were reached through the usage of ultrasonically treated sludge. Regarding economics, reimbursement of the investment was immediate as reduced sewage fees associated with sludge disposal and nitrogen concentrations were achieved. Hence, the advantages are visible from an economic perspective as well as on the operational level itself. Adding to economic advantages, it must be mentioned that the plant avoided being forced into purchasing an external carbon source. The plant was ultimately able to conserve resources, optimize existing process and acquire a higher degree of operational stability through the incorporation of this ultrasound technology.

4. CONCLUSIONS

With regard to anaerobic digestion, it has been proven both on the pilot and in full-scale that digestion is improved through the use of ultrasound to sonicate sludge. The benefits are visible on the operational level and economically. Using experiences from full-scale installations as references, we can gather that the application has proven itself both technically and economically feasible.

Using ultrasound for the purpose of improving aerobic digestion is a quite new application and the mechanisms of the microbiological processes need to be researched further in order to establish the significance of metabolic processes that take place. First experiences with full-scale do, however, indicate that we achieve similar effects in aerobic applications as with anaerobic. That is, bacterial cells are broken apart and destroyed, which means that there is a larger amount of bio-available carbon for the remaining microorganisms to metabolize. The result is intensified denitrification and a reduction of the excess sludge mass. On the operational level, less foaming and bulking sludge is attained, as the organisms responsible for these phenomenons are broken apart or destroyed in treatment process.

REFERENCES

[1] Malina, J.F., Pohland, F.G. Design of anaerobic processes for the treatment of industrial and municipal wastes. In Water Quality Management Library; Technomic Publishing Company: Lancaster, USA, 1992.

[2] Vera, M.A., Nickel, K., Neis, U., Ritchie, J. Disintegration of sewage sludge for improved biodegradation, in: Proceedings of the IWA Specialised Conference on Sewage Sludge, South Africa (Paper 204) 2005.

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

[4] Neis, U., Nickel, K., Tiehm, A. Enhancement of anaerobic sludge digestion by ultrasonic disintegration. Wat. Sci. Tech. 2000 42 (9), 73-80.

[5] Shimizu, T., Kudo, K., Nasu, Y. Anaerobic Waste-Activated Sludge Digestion—A Bioconversion Mechanism and Kinetic Model. Biotechnology and Bioengineering. 1993 41, 1082-1091.

[6] European Union, Community Research and Development Information Service (CORDIS). Project name: Ways of Innovation for the Reduction of Excess Sludge (W.I.R.E.S.). Project reference: EVK1-CT2000-00050. http://cordis.europa.eu, 2007-01-24.