JEE Journal of Ecological Engineering
Volume 21, Issue 3, April 2020, pages 36–40
https://doi.org/10.12911/22998993/118301

Received: 2020.01.15
Revised: 2020.01.30
Accepted: 2020.02.15
Available online: 2020.03.16

Sonification Energy in the Process of Ultrasonic Disintegration

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ABSTRACT
Disintegration of sewage sludge leads to the breakdown of the structure of the sewage floc and release of intracellular fluids. This allows for easy removal of organic compounds that are contained in the cells during further processes of treatment of waste and processing of sludge. One of the methods of disintegration is the use of ultrasound field energy. Depending on the applied process parameters (exposure time, intensity), coagulation or dispersion of the sludge flocs may occur. The aim of the research was to determine the amount of sonication energy supplied to the sludge and the related costs of the disintegration process. The study used digested sewage sludge, which was exposed to ultrasound field energy of different intensity (from 1.6 W/cm^2 to 3.8 W/cm^2) and exposure time (from 2 to 120s). The sewage sludge sonication process was conducted using Sonics VCX-1500 ultrasonic processor with a maximum output power of 1500W. The vibration frequency of the ultrasound field of the generator was 20 kHz, whereas the maximum wavelength for the 100% amplitude, was 39.42 µm. Energy demand was recorded during each measurement and the amount of sonication energy supplied to the system was calculated relative to dry matter. The experiments showed an increase in the demand for energy along with the extension of the exposure time and the increase in the intensity of the ultrasound field. For two of sludge samples with comparable dry matter content, the sonication energy values were similar.

Keywords: sewage sludge, disintegration, sonication energy

INTRODUCTION

The management of sewage sludge as waste has changed dramatically in recent years compared to previously used methods. Nowadays, sewage sludge has become a substrate or an addition to the further use, e.g. in cement plants. Its combustion, co-incineration, and agricultural or natural use (after meeting certain requirements) became the basis for their final disposal. The search for methods intensifying the final dewatering contributes to the understanding of the properties of sewage sludge [Bień et al. 2015]. Among the known methods of conditioning, the most common method is the use of chemical agents in the form of solutions [Zhang et al. 2017]. Other known methods are physical methods and, more recently, more and more popular unconventional methods (ultrasound, electromagnetic or microwave field energy) [Zhou et al. 2014, Wolski et al. 2012, Zhang et al. 2008, Guan et al. 2016, Alaba et al. 2018]. The use of sonication in the sewage sludge conditioning process requires supplying energy [Zielewicz 2016]. Coagulation or dispersion of sludge flocs may be observed, depending on the process parameters (wavelength of ultrasound field, exposure time). The dispersive effect of the ultrasound field energy in the fermentation process is desirable and it is caused by the breakdown of the cell membrane structure, eventually contributing to the intensification of the process [Zhou et al. 2017]. The coagulation effect is also a desirable phenomenon in the process of thickening and dewatering of sewage sludge [Feng et al. 2009].

Sewage sludge disintegration is conducted in order to reduce the phenomenon of sludge swelling, increase in organic matter decomposition in sludge during stabilization and increase in the volume of biogas generated while reducing the amount of sludge prepared for the use [Lu et al. 2018]. Ultrasonic disintegration can also be used for the sanitary stabilisation of sewage sludge. The research described by Nowak, discussing the use of ultrasound to disinfect sludge showed high effectiveness of waves in modification of the microbiological composition of the sludge. The results show that extending sonication time from 10 min to 30 min allowed for almost 100% removal of microorganisms from the sludge tested. The use of the most common method of sludge stabilization, i.e. methane fermentation, shows that sludge is not a sanitary safe product. Therefore, the combination of fermentation with the exposure to ultrasound waves would allow for obtaining a product that is safe and stable in terms of sanitary conditions [Nowak 2015].

The use of disintegration involves the consumption of a certain amount of energy that needs to be supplied to the system in order to achieve the intended effect, e.g. improvement in dewatering efficiency [Grosser et al. 2018]. The aim of the research was to determine the amount of sonication energy supplied to the sludge and the related costs of the disintegration process.

METHODOLOGY

The experiments were conducted using two fermented sludge samples taken from a mechanical-biological treatment plant. The first treatment plant (denoted treatment plant I) receives over 43,000 m^3 of wastewater per day, while the second one (treatment plant II) receives up to 32,000 m^3 of wastewater per day. Dry mass of sludge from wastewater treatment plant I was 21.1 g/dm^3 (14.8 g/dm^3 – content of organic substances, 6.30 g/dm^3 – content of mineral substances), whereas initial water content was 97.89%. Capillary suction time was 609 seconds and the specific sludge resistance was $8.23 \cdot 10^{13}$ m/kg. For wastewater treatment plant II, the values were respectively: dry matter of sludge: 19.8 g/dm^3 (13.6 g/dm^3 – organic matter content, 6.20 g/dm^3 – mineral matter content), initial water content: 98.02%, capillary suction time: 85 seconds, and specific resistance of sludge was $2.42 \cdot 10^{13}$ m/kg. Dry mass content and initial water content of sludge was determined based on the standard PN-EN-12880. The Sonics VCX 1500 ultrasonic processor with a frequency of 20 kHz and an ultrasound field wavelength of 39.42 μm (100%) was used for sonication. The continuous ultrasound process was carried out using five values of ultrasound field intensities: 1.6; 2.2; 2.7; 3.2; 3.8 W/cm^2, corresponding to wavelengths of 7.88; 15.77; 23.65; 31.54; 39.42μm. The time during which energy was supplied to the system was respectively: 2; 5; 10; 20; 30; 45; 60 and 120 second. The device is used to transform electricity into mechanical energy supplied to the titanium tip in the form of wave. The amount of energy supplied to the system was read after each measurement. Volume of the samples exposed to ultrasound field was 150 cm^3. The amount of sonication energy supplied to the system was calculated from the formula:

$$ES = E/(V \cdot s.m.), \text{ kJ/kg d.m.} \tag{1}$$

where: E – acoustic energy, J
V – sample volume, cm^3
$s.m.$ – dry matter of sludge, g/dm^3

RESULTS AND DISCUSSION

The ultrasound disintegration performed continuously for sludge I showed a change in the value of energy introduced depending on the wave intensity of the ultrasound field and the exposure time. For all the ultrasound field wave intensities used in the study, an increase in energy demand was observed with the exposure time (Fig. 1). For the highest ultrasound field intensity (3.8 W/cm^2), the amount of energy supplied to the system during 2 seconds of sonication was $0.082 \cdot 10^{-3}$ kWh. This value rose to $0.23 \cdot 10^{-3}$ kWh for 5-second sonication. Another twofold increase ($0.59 \cdot 10^{-3}$ kWh) was observed when disintegration with ultrasound field was doubled (10s). The analogy was observed until the completion of the disintegration process, with the value of energy demand at the level of $6.65 \cdot 10^{-3}$ kWh obtained for 120 s.

In case of using ultrasound field with lower ultrasound field intensity (3.2 W/cm^2), the reduced energy demand was shown for all the sonication times. In the case of 10 seconds, this was $0.49 \cdot 10^{-3}$ kWh. For 120-second sonication, the energy demand for the ultrasound field intensity of 3.2 W/cm^2 was also lower by $1.64 \cdot 10^{-3}$ kWh compared to ultrasound field intensity of 3.2 W/cm^2 (Fig. 1).

The analysis of other ultrasound field intensities (1.6; 2.2; 2.7 W/cm^2) showed the same

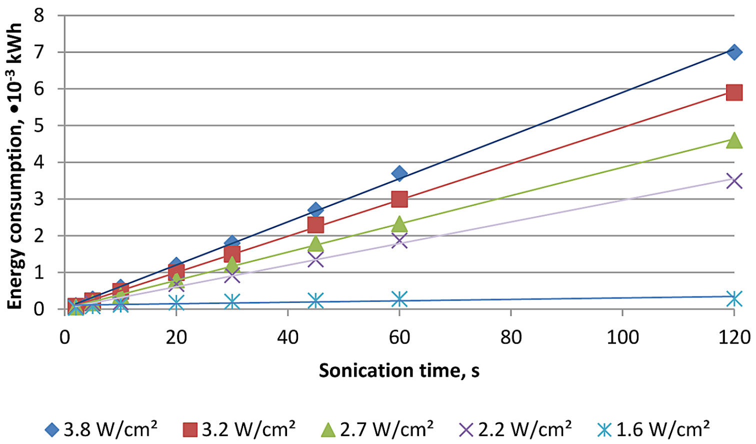

Fig. 1. Effect of sonication time and ultrasound field intensity on energy demand (sludge I)

relationships as in the case of the ultrasound field intensities discussed above. The lowest energy demand of 0.023•10^{-3} kWh, which was supplied to the system in the research, was recorded for 2-second sonication for the ultrasound field intensity of 1.6 W/cm^2 (Fig. 1).

For sludge II, the experiment based on a continuous ultrasonic disintegration process showed results similar to sludge I. The consumption of energy supplied to the system also depended on sonication time and ultrasound wave intensity. For each of the five wave intensities used, a proportional increase in the introduced energy was noticed along with the increase in the sonication time (Fig. 2). For the longest sonication time of 120 seconds and wave intensity of 3.8 W/cm^2, energy consumption was 6.64•10^{-3} kWh. This value almost doubled for the 60-second sonication to 3.52•10^{-3} kWh (Fig. 2). The smallest energy consumption of 0.023•10^{-3} kWh was recorded at 1.6 W/cm^2 and sonication time of 2 seconds.

Energy consumption correlated with the amount of sonication energy supplied to the system. An increase in sonication energy was observed for the sludge samples studied along with the sonication time and ultrasound field intensity. The highest amount of energy of 8.064 MJ/kg d.m. was supplied for sludge I, for ultrasound field intensity of 3.8 W/cm^2 and sonication time of 120 seconds. For the ultrasound field intensity of 1.6 W/cm^2 and time of 120 seconds, the value of sonication energy supplied to the system was reduced to 2.898 MJ/kg d.m. The lowest value of sonication energy of 0.027 MJ/kg was recorded for sludge 2 at ultrasound field intensity of 1.6 W/cm^2 and sonication time of 2 seconds.

CONCLUSIONS

The aim of the research was to evaluate the energy demand and to calculate the sonication energy supplied to the sludge samples studied

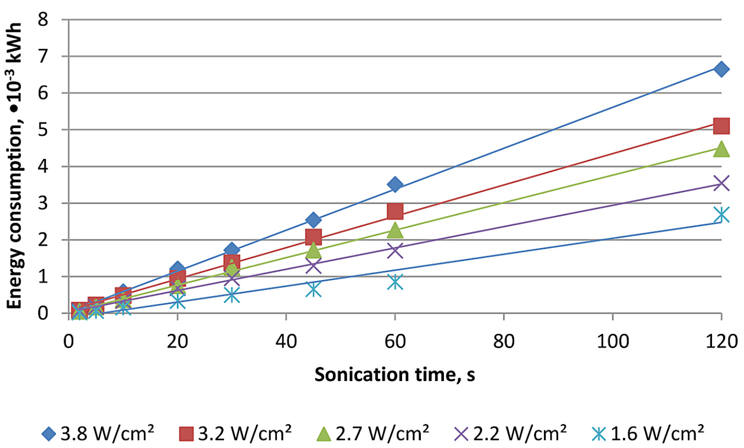

Fig. 2. Effect of sonication time and ultrasound field intensity on energy demand (sludge II)

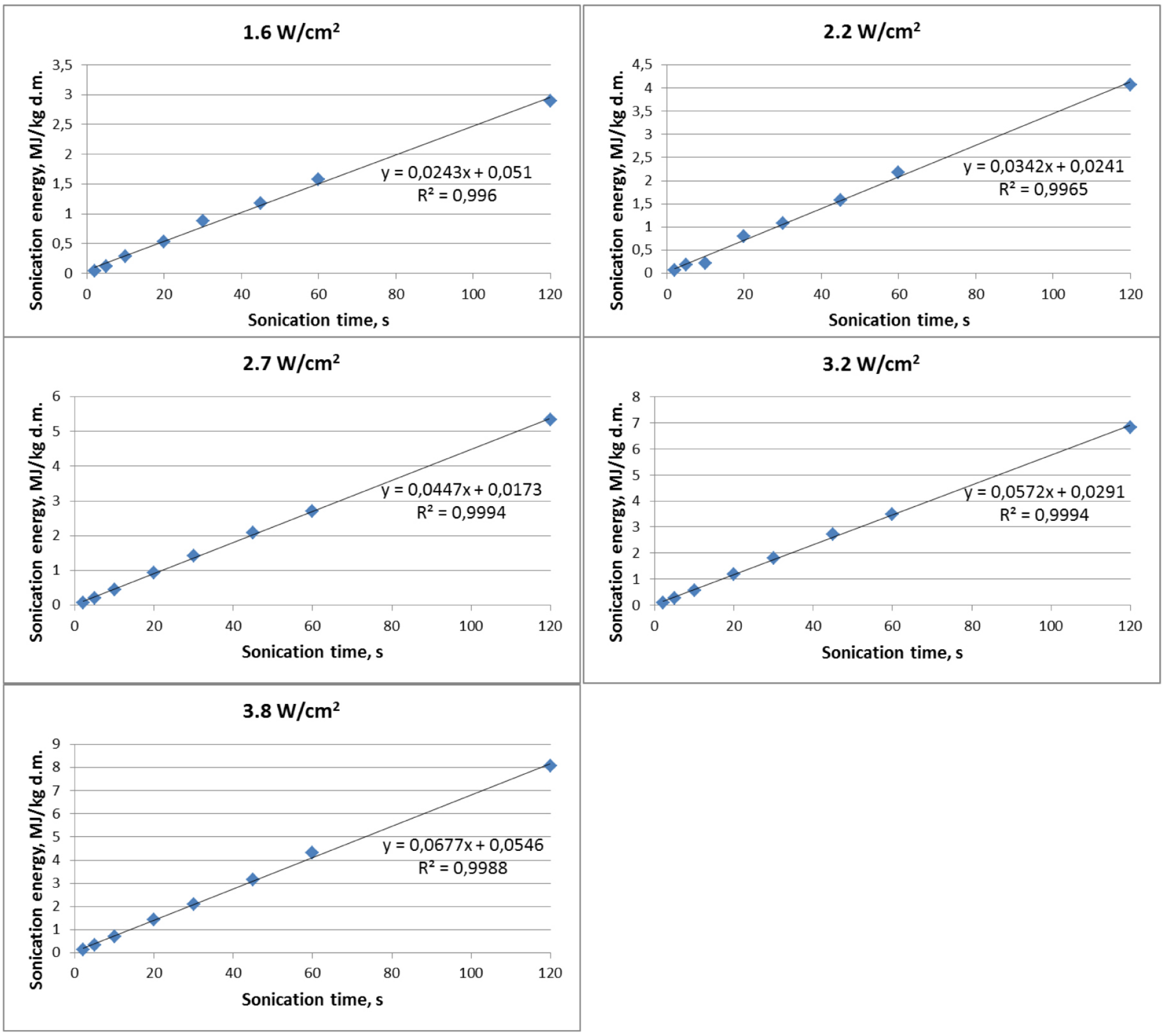

Fig. 3. Sonication energy supplied to the sludge depending on ultrasound field intensity and the sonication time (sludge I)

relative to dry matter. Two types of sewage sludge with similar dry matter contents were used in the experiment: sludge I (21.1 g/dm^3) and sludge II (19.8 g/dm^3). Sewage sludge was exposed to different sonication times (2, 5, 10, 20, 30, 45, 60, 120 seconds) and different values of the ultrasound field intensity (1.6, 2.2, 2.7, 3.2, 3.8 W/cm^2).

The analysis of the results showed that the energy consumption values for the two types of sludge tested were similar. The amount of energy consumed was affected by sonication time and ultrasound field intensity. A similar pattern was also observed for the evaluation of the amount of sonication energy introduced into the sludge relative per dry matter. Also in this case, the values of sonication energy supplied to the sludge were comparable. Only sonication time and the values of ultrasound field intensity had an effect on the amount of energy supplied to the sludge relative per dry matter.

The values obtained will allow for the assessment of the usefulness of the exposure to ultrasound field for sewage sludge disintegration. Application of sonication in some processes, e.g. dewatering, may not be economically viable, while in others, e.g. decomposition of the floc structure before the fermentation process, may result in intensification of the process, resulting in an increase in biogas production. Each type of sludge is different and therefore preliminary testing is needed to determine the usefulness of a specific disintegration method. It is important that energy costs are not higher than the effects achieved, although in some cases the environmental factor may be more important than economic criteria.

Acknowledgements

The research was funded by the project No. BS-PB-401/301/11

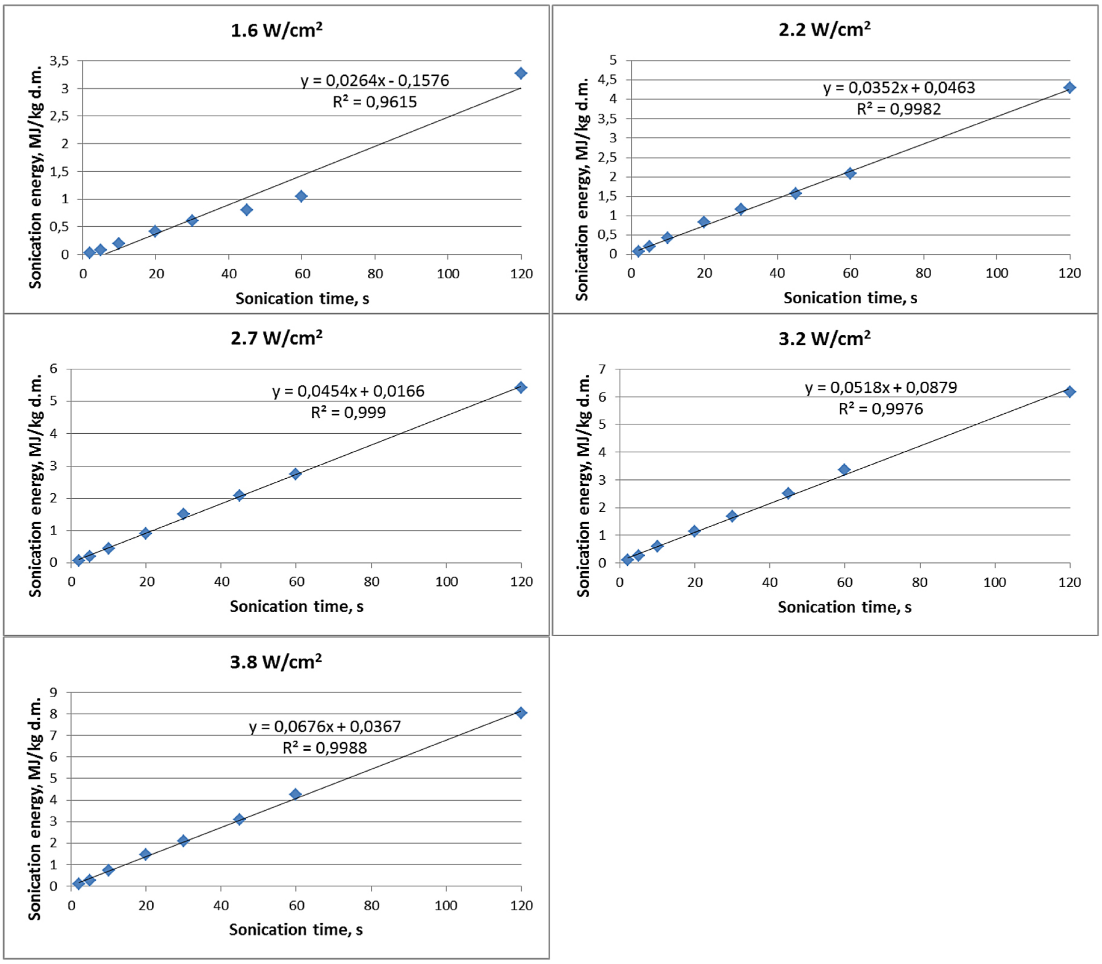

Fig. 4. Sonication energy supplied to the sludge depending on ultrasound field intensity and the sonication time (sludge II)

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