Combatting bulking sludge with ultrasound

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Abstract

Bulking and floating sludge cause great problems in many waste water treatment plants with biological nutrient removal. The purification as well as the sludge digestion process can be affected. These problems are due to the interlaced structure of filamentous microorganisms, which have an impact on the sludge's settling behaviour. Foam is able to build up a stable layer, which does not settle in the secondary clarifier. Foam in digestion causes a reduction of the degree of stabilisation and of the biogas production.

We use low-frequency ultrasound to combat filamentous organisms in bulking sludge. Low-frequency ultrasound is suitable to create high local shear stresses, which are capable of breaking the filamentous structures of the sludge. After preliminary lab-scale tests now a full-scale new ultrasound equipment is operating at Reinfeld sewage treatment plant, Germany. The objective of this study is to explore the best ultrasound configuration to destroy the filamentous structure of bulking and foaming sludge in a sustainable way. Later this study will also look into the effects of ultrasound treated bulking sludge on the anaerobic digestion process. Up to now results show that the settling behaviour of bulking sludge is improved. The minimal ultrasound energy input for destruction of bulking structure was determined.

Analysis of bulking problems

On many waste water treatment plants frequently problems occur with excessive growth of filamentous micro-organisms. Filamentous organisms grow out of the activated sludge flocs and lead to a diffuse and very irregular shape of the activated sludge flocs. This phenomenon can be either categorised as bulking sludge, floating sludge or foam. Bulking sludge is defined as sludge with a sludge volume index (SVI) of more than 150 mL/g. Floating sludge or foam builds a stable layer at the surface of the aeration basin or final clarification basin. Any of these problems lead to an increased suspended solid content in the effluent of the sewage treatment plant (STP).

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Moreover, these phenomena have an impact on the subsequent anaerobic treatment. Foam in the digester causes a reduction of the degree of stabilization and of the biogas production. In the worst case the anaerobic stabilization process will be made impossible. There are a number of factors influencing the growth of filamentous organisms. Above all low-loaded waste water treatment plants with biological nutrient removal offer selection advantages to some filamentous organisms (e.g. *Microthrix parvicella*; *nocardioforme actinomycetes*) [Knoop et al., 1998]. Low organic sludge loads (< 0.1 kg BOD5/(kg_{TSS} * d)), low waste water temperatures (12-15°C) and high sludge ages are considered as favouring factors to the abundant development of *Microthrix parvicella*, which is the most frequently occurring organism [Knoop et al., 1998].

Often non-specific methods are used to combat bulking or floating sludge. The use of aluminium and iron salts or the application of strong oxidizing agents belongs to these methods. One disadvantage of using chemicals is, that floc forming bacteria are also influenced negatively. This can lead to the failure of the treatment process [Lemmer, 1996]. Additionally the use of chemicals results in an increase in sludge mass, which has to be disposed. Theoretically, the massive growth of filamentous organisms could be avoided by increasing the sludge load, but a higher sludge load leads to a decrease of the sludge age [Denkert, 2001]. Then nitrifying bacteria with long generation times are carried out of the system. The result would be an increased nitrogen concentration in the effluent of the STP. The cause for the excessive growth of filamentous organisms can be combated by specific measures. For example by an improvement of the waste water quality (e.g. the prevention of H_2S formation) or by modifications in the operation mode (e.g. aerobic selector) filamentous organisms are carried out of the system. These methods are comparably more extensive and do not work in every case of bulking or floating sludge problems.

The method presented in this paper to combat filamentous sludge is the application of ultrasound. The destruction of the filamentous sludge structure is mainly caused by hydromechanical effects in the advent of the collapse of cavitation bubbles generated by ultrasonic waves. Details about the formation and the action of cavitation bubbles are given elsewhere [Neis et al., 1999]. By cavitation powerful currents (jet streams) are created, which lead to high mechanical shearing forces in the liquid. The mechanical shear stresses are able to destroy the filamentous network of bulking or floating sludge. Also gas bubbles are set free. The thin filaments are much more exposed to the shearing forces than the flocs and are cut up into small pieces. Since the remaining flocs are not interconnected by filamentous organisms any longer, the activated sludge flocs become smaller and much more compact after sonication [Nickel, 1999]. The smaller floc size improves the settling properties of the activated sludge in the secondary clarifier. Due to the smaller size, bacteria are better provided with substrate, which increases their selection advantage against the filamentous organisms [Müller et al., 1999].

King & Forster (1990) investigated the effect of activated sludge sonication (20 kHz Dawe Soniprobe 7530A, Dawe Instruments Ltd, London, UK) on particular characteristics. The sludge SVI values dropped steadily with an increasing ultrasonic power input up to 25 Wh/L.

However, the improvement of sludge settleability was achieved at the expense of the supernatant clarity. The SVI was reduced to about 40% of the initial value at a dose of 15 Wh/L. By a further increase of the sonication dose the SVI began to stabilise and a large number of free microorganisms could be observed by light-microscopical analysis.

Jorgensen & Kristensen (1996) also suggest that sonication might have a potential as a new method to control the growth of filamentous bacteria in activated sludge. According to microscopic analysis the laboratory sonication (RESON SYSTEMS AS, frequency 25-30 kHz) for 2 seconds at a dose of 0.5 Wh/L reduced significantly the number and length of the filamentous microorganism *Microthrix parvicella*. However, the morphological and mechanical characteristics of the filamentous bacteria must be considered and ultrasonic treatment have to be adjusted. Thus sonication of the thicker and more robust filament type 021N took much longer time and higher power levels to destroy the filamentous organisms as compared to activated sludge with dominating growth of *Microthrix parvicella*.

So we assume that mechanical treatment is suitable to destroy the filamentous structure of activated sludge. As a result the subsequent anaerobic stabilization becomes possible. The operating problems will be considerably reduced due to the prevention of foaming during biogas production [Barjenbruch *et al*., 1999; Müller, 1999].

Objective of the study

The filamentous structure of bulking sludge is a dominant cause for sludge floating in the digester. More than that gas bubbles are trapped in the filamentous network and support the upflow of the sludge. This study focuses on the determination of an optimal ultrasound configuration in order to eliminate in a sustainable way problems associated with the growth of filamentous organisms in waste water treatment and sludge digestion. One important criterion for the real-scale practicability of the ultrasonic application is to minimise the energy input necessary to destroy the filamentous network.

Another important objective is to guarantee the effectiveness of the digestion process: the biogas production and the degree of sludge stabilisation have to be maintained or better even should be improved. The re-growth in the aeration basin of filamentous micro-organisms by the return flow from the digesters has to be prevented.

This paper deals with preliminary investigations, which look into ways how to define the effectiveness of sonication of bulking activated sludge. A continuous lab-scale activated sludge reactor was used to grow bulking material. Ultrasound experiments were first done as batch type lab-scale tests. Actually full-scale tests are under way and first results derived from these tests are also presented.

Materials and Methods

Lab-scale batch tests

Sonication of bulking sludge samples in our batch tests was executed by a single horn sonotrode with a diameter of 1.9 cm². The sonotrode was operated at a frequency of 20 kHz and a high acoustic power density of 55 W/cm². Irradiation doses were between 2.6 and 15.0 Wh/L. In order to minimize the energy input sonication times ranged between 10 and 90 seconds. The energy input was quantified as specific energy in [kWh/kg DW]. The specific energy relates the power input and the sonication time to the dry weight (DW) of the treated sludge. The waste activated sludge samples were taken from the municipal waste water treatment plant at Reinfeld, Germany, where severe problems are occurring with foaming sludge in the aeration basin, final clarification and in the anaerobic tank.

The effects of sonication were evaluated by microscopic examination and settling experiments by which the sludge volume index (SVI) is determined. It relates the sample volume after a settling period of 30 minutes to the total suspended solids concentration (TSS). Bulking sludge is indicated by SVI values higher than 150 mL/g (ATV-working group 2.6.1, 1988).

Continuous lab-scale experiment

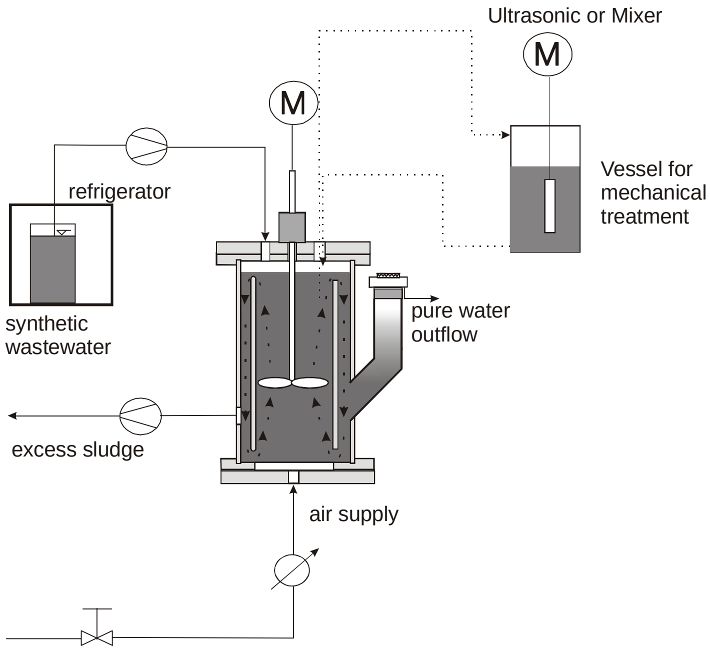

Figure 1: Laboratory waste water treatment

The experimental setup is shown in figure 1. The main element is the aeration tank of a volume of 10 litre with an integrated separator. The aeration of the tank is provided by means of a diaphragm at the bottom of the reactor. Two reactors were operated in parallel one as control the second to explore the effect of sonication on the activated sludge structure. Three litre of activated sludge were taken daily out of reactor 1 and treated with ultrasound. After that the sludge was pumped back in the reactor.

The sludge index was observed during the time of the experiment. The sludge was examined under the microscope and the amount of filaments was measured by image analysis.

Full-scale continuous experiments

The full-scale experiments were done with a new ultrasound reactor manufactured by SONOTRONIC GmbH, Ittersbach, Germany, shown in figure 1.

Figure 2: Full-scale ultrasound module, Sonotronic GmbH, Ittersbach, Germany.

This module works at a frequency of 20 kHz, sonication time was about 90 seconds at a volumetric sludge flow of 16 L/min. The irradiation doses ranged between 3.1 and 5.3 Wh/L. The tests are done at the municipal waste water treatment plant at Reinfeld. Waste activated bulking sludge pumped from the seondary settling tank to the ultrasound reactor, which is mounted in a container close by.

Results and discussion

The effect of sonication on the filamentous organisms is evident from the photos shown in figure 3, 4 and 5. In the control sample (fig. 3) a large number of filaments is present causing the threadlike structure of the sludge. Even a low energy input of 0.05 kWh/kg causes damage to the filamentous structure (figure 4). A large number of broken filament segments can be observed.

The reduction of the filament length is sufficient to improve the settling behaviour (fig. 6a). The increase of the energy input of about 0.2 kWh/kg causes further cut of the thread segments (fig. 5) and improves the settling behaviour (fig. 6a+b). Figure 5 shows that there are only a few long filaments left while the number of free bacteria in the water phase increases.

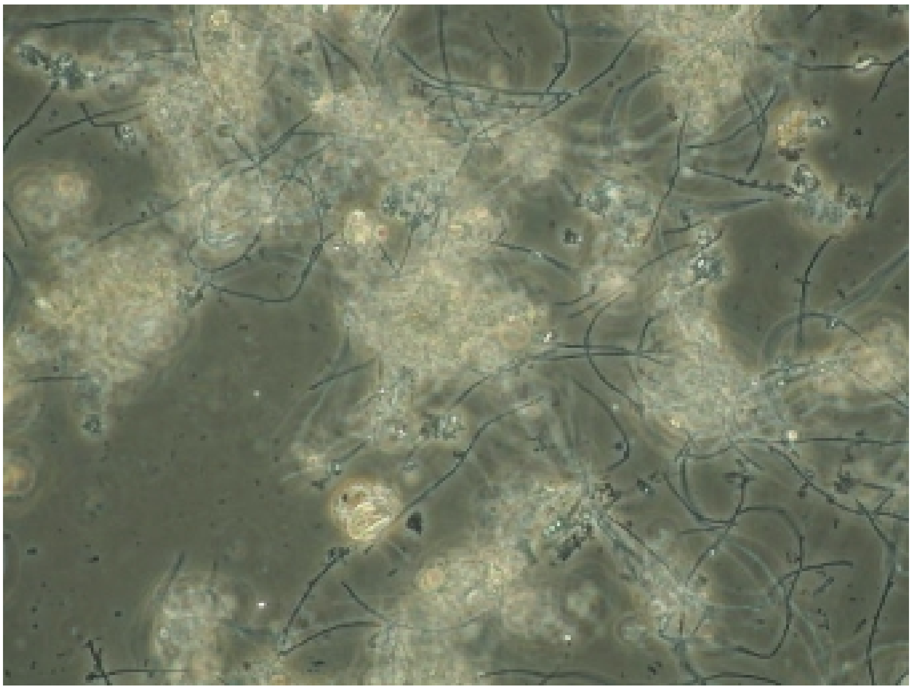

Figure 3: Light-microscopical image of untreated activated sludge, enlargement factor 400, sample corresponds to figures 6a and 6b.

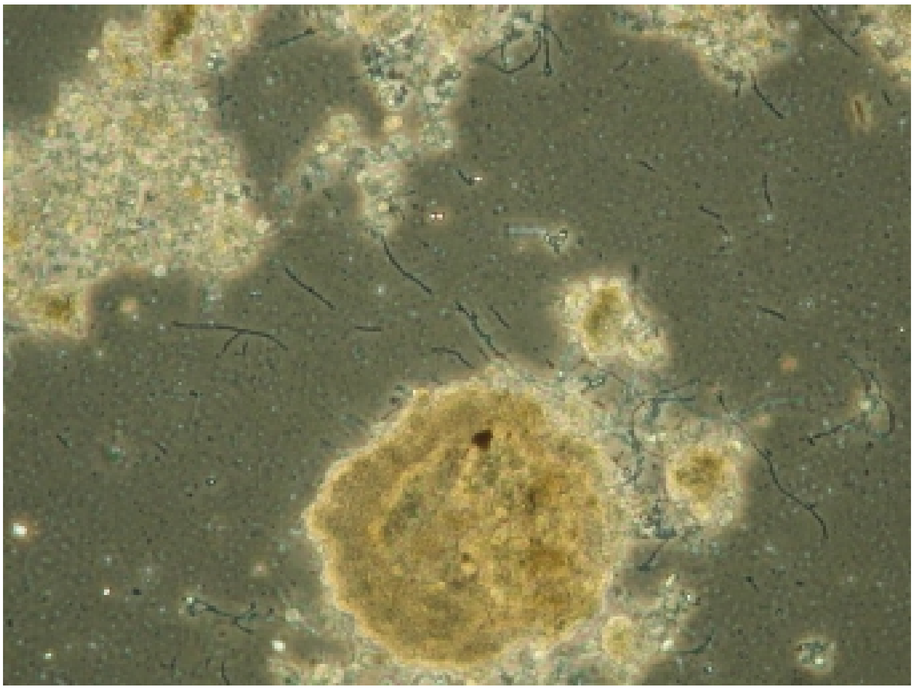

Figure 4: Light-microscopic image of sonicated sludge (specific energy input 0.05 kWh/kg_{TSS}), enlargement factor 200, sample corresponds to figures 6a and 6b.

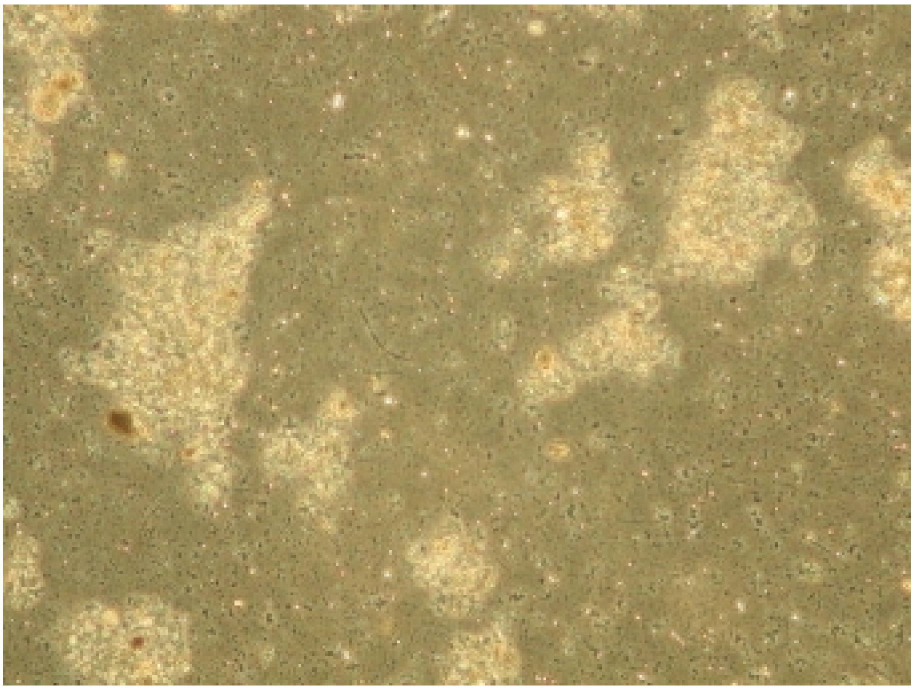

Figure 5: Light-microscopic image of sonicated sludge (specific energy input 0.2 kWh/kg_{TSS}), enlargement factor 100, sample corresponds to figures 6a and 6b.

Lab-scale batch tests

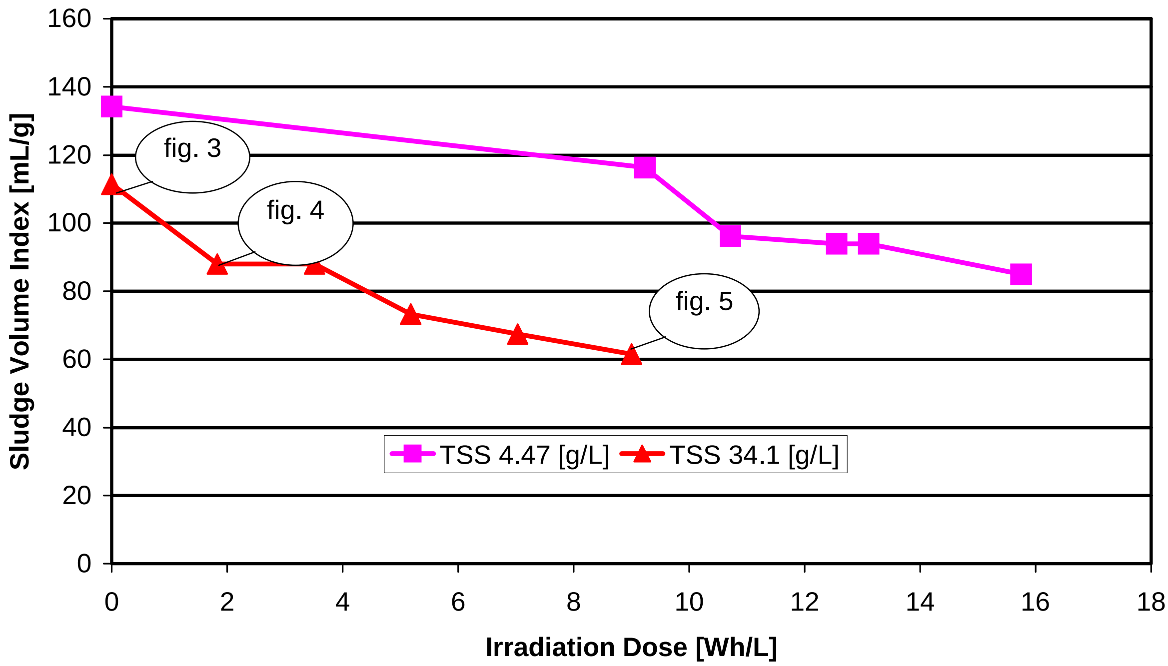

Figure 6a: Sludge volume index as a function of irradiation dose; samples from the STP Reinfeld, Germany. Lab-scale.

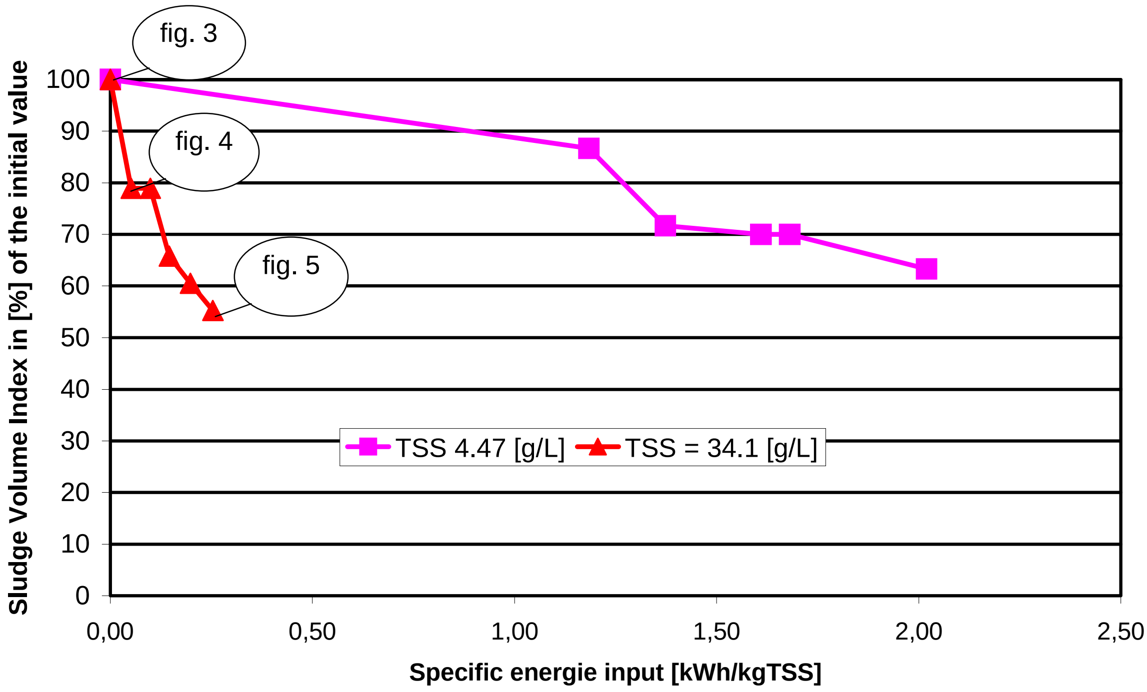

Figure 7b: Sludge volume index at different specific energy inputs; samples from the STP Reinfeld, Germany. Lab-scale.

In earlier investigations it was already stated that the treatment of activated sludge with ultrasound has a positive effect on the sedimentation behaviour [Tiehm et al. 1998]. Our lab scale experiments were done in with a maximum intensity level of 155 W and short sonication times (10-90 s). The initial of the sludge volume index values were below 150 mL/g. Nevertheless the sludge showed a quite high amount of filaments (fig. 3) and the settling behaviour was improved by the ultrasonic treatment. The results of the settling experiments are shown in figure 6a. The best results were obtained at an applied dose of 9 Wh/L for sludge with TSS-concentration of 34 g/L. The sludge volume index was reduced to 62 mL/g as compared to 111 mL/g for the untreated sample. Sludge with lower TSS-concentrations need a higher irradiation dose as shown for the sludge concentration of 4.5 g_{TSS}/L.

Figure 6b shows that the relative improvement of the sludge index is better for sludges with high total suspended solids concentration. In lab scale the SVI was reduced to about 55% of the initial value for sludge with a TSS-concentration of 34 g/L at a specific energy input of 0.2 kWh/kg_{TSS}. The SVI of another lab scale experiment was reduced to about 63% at a specific energy input of 2.0 kWh/kg_{TSS}. The higher the total suspended solids concentration is the more effective is the treatment with ultrasound.

Continuous lab-scale experiment

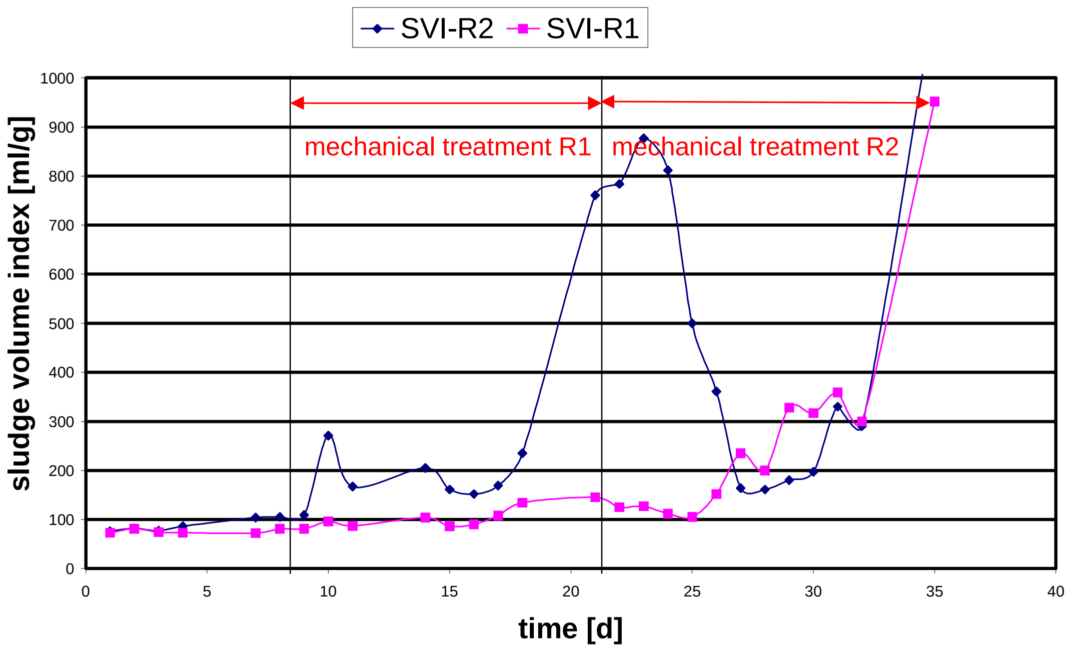

Figure 8: Development of the sludge volume index with time

The results of the continuous lab-scale experiment show that the ultrasonic treatment is an effective way in order to suppress an excessive development of filamentous organisms. During the sonication period of reactor 1 in the first part of the experiment the sludge volume index was kept below 150 mL/g. Later reactor 2 was sonicated in the second part of the experiment. This was only successful for a short period. After approximately 5 days the sludge volume index rose again. One explanation might be the decrease of the TSS-concentration at the end of the experiment, which is not favourable for the effectiveness of ultrasound.

Full-scale continuous experiment

In the executed full-scale experiments the sludge volume index was also reduced. The initial SVI value again was below 150 mL/g. The results of these first full scale tests are shown in the figures 8a and 8b. The best results are observed at an applied dose of 5.3 Wh/L for sludge with TSS-concentration of 30.4 g/L. The sludge volume index was reduced to 60 mL/g compared to 90 mL/g for the conrol sample.

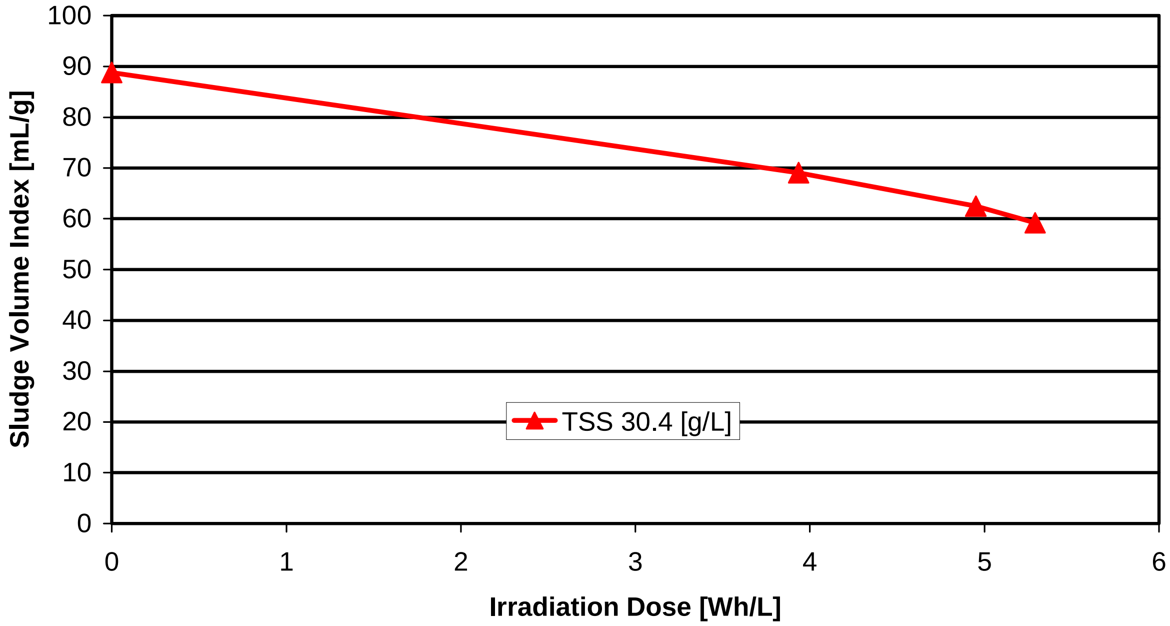

Figure 9a: Sludge volume index as a function of irradiation dose; samples from the STP Reinfeld, Germany. Full-scale.

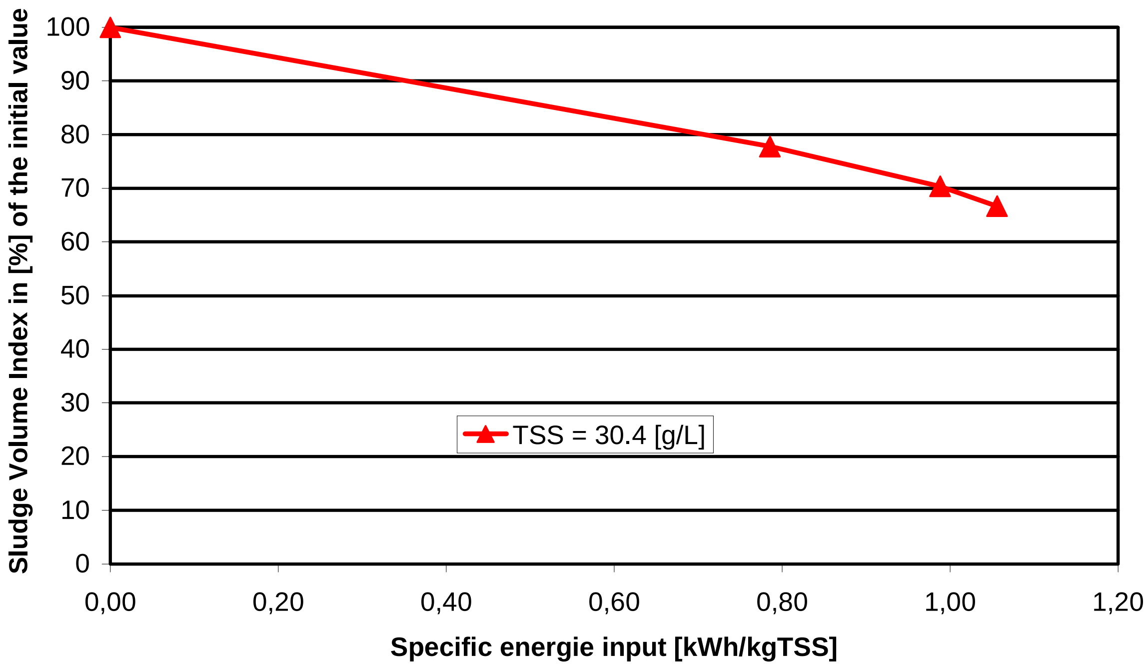

Figure 8b: Sludge volume index at different total specific energy inputs; samples from the STP Reinfeld, Germany. Full-scale.

The SVI was reduced to about 68% of the initial value. In this experiment the input parameters were a specific energy input of 1.0 kWh/kg and a TSS-concentration about 30 g/L.

In the full scale experiments a higher irradiation dose to obtain the same reduction of the SVI is needed for sludges with similar TSS-concentration as compared to lab scale. The energy input in the full scale tests shown above is derived from the total power consumed since the net energy input was not yet determined at that point in time while for the graph showing the lab tests results the net energy input was taken. Further full scale experiments are necessary to verify or discard this observation and to find out the reasons for that.

We also found that the effects of acoustic irradiation on filamentous organisms can rather be detected by microscopic examination than by determination of the sludge volume index. The parameter sludge volume index is not a good criterion either to evaluate the amount of filaments in the sludge. Actually we examine other parameters like hydrophobicity, capillary suction time, etc., which might be better suited to assess the effects of mechanical destruction of bulking sludges.

Conclusions

Only small energy inputs are necessary in order to destroy the filamentous sludge structures. In this regard ultrasonic treatment of the return sludge from the secondary clarifier is an interesting approach to overcome problems with floating suspended matter discharged from secondary clarifiers, which could be eliminated without using chemicals. Nevertheless the general suitability of the ultrasound procedure as treatment of bulking waste activated sludge in order to avoid foaming in the digestion tank has to be verified by ongoing full scale investigations.
Also more full scale experiments are needed to better assess the influence of sludge parameters like TSS on the one hand and ultrasound related parameters like acoustic dose on the other hand on the treatment result.

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