EFFECTS OF PULSED ELECTRIC FIELD (PEF) APPLICATION ON ACTIVATED WASTEWATER TREATMENT SLUDGE *

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Abstract

In activated sludge processes wastewater compounds are converted by micro-organism, resulting into biomass by growth processes. The biomass, also presenting a substrate, is bound to the micro-organism and can cumbersome be further degraded. Finally a huge amount of excess sludge is build during the cleaning processes which have got to be disposed, while evoking high costs. Many so called disintegration techniques are now applied to evoke the death and lysis of the micro-organism in order to encourage their degradation in a following treatment step. The implementation of the pulsed electric field (PEF) treatment is being tested in this sector. This research focuses on the effects of PEF application on the complicated living space of organism in the sludge. The sludge is dominated by the characteristic that the predominant part of the micro-organism agglomerate in flocs, bound together by extracellular polymeric substances (EPS). The direct impact on the activated sludge has been examined by particle sizemeasurements, organic content release and activity of micro-organism. By the research it is shown that the uptake of organic content release does not evoke a parallel destroying of the structure, seen in the results that the particle size distribution. Concerning the activity it is shown, that the activity decreases with increasing field strength.

INTRODUCTION

Nowadays waste water treatment plants have got to cope with the task of sludge management as a consequence of its high disposal costs. Implementing sludge disintegration in the stage of wastewater treatment or in the sludge stage is a possible strategy of sludge minimisation. The aims of sludge disintegration are floc destruction and cell disruption, which release solubilised organic matter, improve aerobic or anaerobic degradation and reduces excess sludge production, change settling properties and reduce bulking and scumming [1][2]. Many sludge disintegration technologies are being explored, e.g. stirred ball–mill, ultrasonic disintegrator, ozone. The pulsed electric field (PEF) treatment can also be implemented for the release of sludge components. In comparison to other techniques the special characteristic of the PEF implementation are its predominant effect on cell membranes. By theory PEF implementation influences sludge structure less than other disintegrative mechanical methods which effects base on primary floc and following cell rupture. So far the inactivation of micro-organism by PEF has been intensively investigated in the food-industry as an alternative non-thermal technology to the conventional thermal treatment [3]. Concerning the sludge only some researches have been realised [4][5].

In general wastewater sludge can be introduced as multi-compartment liquid containing particulate organic and inorganic material, micro-organisms as alive and dead bacteria, filament bacteria, eukaryotes, and EPS. The main part of the content is aggregated to flocs by means of the EPS, which is produced by the bacteria. The flocs are very heterogeneous by content, size, pore spaces and water channels. The physicochemical characteristics of flocs influence many of the steps involved in waste water treatment including substrate transfer and utilization, floc formation and break-up, supernatant filtration, biosolids thickening via sedimentation and/or flotation, and dewatering [6]. While approaching to the structure different models can be found depending on their main focus. Concerning size measurements Jorand et al. and Snidarò et al. [7][8] stand in for a two dimensional size model of activated sludge flocs as given in Figure 1. This model subdivides the internal structure of flocs in micro-flocs bound by a different polymer. The morphology can be described as self-similar and characterized by fractal concepts [9]. In case sludge deflocculation appears different mechanism can take place like EPS solubilisation, solubilisation with fragmentation, proliferation of filaments, floc break-up and erosion [10].

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![Figure 1: Two dimensional model [7,8.](image)]
In the last years one flock characteristic has become important. In modern plants with enhanced nitrogen and phosphorus removal a massive growth of filament bacteria is often evoked. The filaments produce open structures which are followed by unwished bulking and foaming of the sludge.

MATERIALS AND METHODS

PEF treatment

The exponential decreasing pulses were applied with a high electric field apparatus working with voltages up to 20 kV. The PEF facility was modified by using capacities from 20 nF up to 50 nF between the resistor R of 100 kΩ and the spark gap. The discharge voltage of C and the field strength across the treatment chamber were adapted by the spark gap. A co-linear treatment chamber with an electric field parallel to the sludge flow was used. The electric energy input in equation 1

\[ E_p = n \cdot \frac{1}{2} \cdot C \cdot U_0^2 \]  

was estimated by number of pulses n, the capacity C, and charging voltage U₀ at the generator. The parameters of PEF-treatment are a field strength of E=7 to 19 kV/cm, a frequency of 20 to 80Hz, a resistance of about 1 kΩ in the treatment chamber and an energy input of \( E_{\text{pe}} = 70-250 \text{ kJ/kg liquid activated sludge} \). The electric energy input was experimentally confirmed by measuring to ohmic heating, thus thermal energy

\[ E_h = m \cdot c \cdot \Delta T \]  

by the help of the temperature difference \( \Delta T \) of the sludge. The heat capacity of water \( c=4.187 \text{ kJ/(kg·K)} \) was assumed for the sludge, though it is lowered by the suspended solids (SS).

Analysis

Samples were taken from the wastewater treatment plants (WWTP) Gelsenkirchen-Picksmühlenbach from the Emscher-Genossenschaft, Germany and Stahnsdorf from the Berliner Wasserbetriebe, Germany. Suspended Solids (SS) and volatile suspended solids (VSS) have been determined according to the German Standard DIN 38409-1 [11]. Microscopic pictures were taken and filament bacteria were determined by Crystal Violet Sheath Stain according to Knoop [12].

For particle size measurements a scanning laser microscope, the MTS Particle Analyser, with a three-fold dynamic optical back-reflection measurement (3D ORM) patented by MTS, Germany, was used. The laser beam scans only subjected particles, which directly come in the focus. In order to focus all particles, a turbulent mixing of the suspension was evoked by stirring at a speed of 200 min⁻¹ and a special form of the beaker used to prevent a uniform drift. No flock breakage evoked by the stirring, seen as evident alteration of the results, was observed at this speed. Each measurement amount from 2000 to 3000 counts per measurement and five measurements were averaged for the evaluation. The measurement range was 0.1 μm to 2000 μm or 0.5 μm to 2000μm. The evaluation was done with the software WinOrm 4.57 which correlates to DIN ISO 9276-2 [13] and the illustration of the programme is according to DIN ISO 9276-1 [14].

A reference measurement was done with the Sysmex FPIA-3000. The Flow Particle Image Analyzer uses a photographic system. While the sample is passing through a measurement cell images of the particles are captured using stroboscopic illumination and a CCD camera. The digital photos are evaluated by the means of an image processor by means of the contrast of pixels.

Before measuring the chemical oxygen demand (COD) and the dissolved organic carbon (DOC) the supernatant was filtrated at a pore size of 0.45 μm. COD was measured by COD-cuvettes made by Dr. Lange. The DOC values according to DIN EN 1484 [15] were measured with Shimadzu TOC-5000.

For the degree of cell disruption the biochemical parameter COD is suitable parameter. The maximum releasable organic compounds (CODr) can be released by adding 1-molar sodium hydroxide [1]. The degree of release can be evaluated using the CODr of the untreated and the CODt of the treated sludge. In this research they have been substituted by the DOC values according to eqn. (3) as follows:

\[ DD_{\text{DOC}} = \frac{[\text{DOC}_u - \text{DOC}_t]}{[\text{DOC}_u - \text{DOC}_t]} \times 100\% \]  

By the dehydrogenase assay (DHA) the enzymatic activity of the bacteria was measured. The test was introduced by EWALD et al. [16]. An adopted and slightly modified form is described in KONERS et al. [17].

RESULTS AND DISCUSSION

The effect of PEF implementation on sludge was analyzed by different techniques. Firstly microscopic pictures were taken as presented in figure 2. In the flock structure between untreated and PEF treated sludge no evident change is seen, but in the liquid more small particulate particles can be detected as spots (Figure 2B). In samples stained with Crystal Violet Sheath Stain filament organism can be detected (Figure 2A and B).

The inner flock size structure was not effected by the treatment, but at the edges the structure appears to be disturbed and the amount of particle in the liquid increased as well. In order to prove this qualitative result particle measurements with the MTS Particle Analyser and FPIA-3000 were implemented.

For the particle size measurements with the MTS Particle Analyzer two different kinds of sludge have been taken. The results are presented in Table 1 and Figure 3. The first sludge is an ordinary well settling sludge and second one a foam, which settles badly and has got a high content of filament micro-organism.
In Table 1 the reference diameter of the volume $d_{50,3}$ is given for 25%, 50% and 99% of the counted particles. By the PEF treatment the particle size of sludge changes a bit and it can reduce as well as increase a bit which sometimes leads to a transient flotation. The flotation disappears after mixing or shaking of the sample. The minor decrease can be evoked by a floc erosion and huge solution of small particles. In case of an increase in floc structure the input of electric load may have changes the surface charge of the flocs and reduced the repletion, so that some particles may agglomerate in a rather coincidental form which binding is not very intensive.

Concerning the foam the thermal treatment did not affect the size, but the PEF treatment reduced the sizes. As the foam can be characterized as flocs of a huge size which structure is dominated by filament micro-organism. Surplus outstanding filaments often suggest a bigger size than the one of the floc nucleus. By the PEF treatment the membrane structure of the filament is structurally weak by perforation and thus less flexible and resistant against outstanding forces. Further on the floc seems to have a solid structure in comparison to the surrounding water. Shear force act most probable near the surface of the floc and filaments, which stick out the surface, are cut off. The sizes of 99% of the particles correspond, so it can be concluded that the filaments are not completely shear off at the floc surface at the implemented energy input of 50kJ/kg.

In order to prove the assumption a further particle size measurement with Sysmex FPIA-3000 was implemented. This particle measurement offers an evaluation of circularity shown in Figure 4. The corresponding figures of Figure 4 are given in Table 2. A circularity of 1 describes a circular form and 0.2 five times longer than wide particles. From the graphic it can be seen that the circularity of the PEF treated sample increases whereas the diameter $d_{50,3}$ keep stable at 6.07μm. The lower limit of recorded data is 2μm. Hence small new generated particles do not affect the results.

![Figure 2: Microscopic pictures of (A) untreated sludge, (B) treated at 14 kV/cm, (C) Crystal Violet Sheath Stain untreated and (D) treated at 14 kV/cm.](image)

<table>
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<th>Treatment</th>
<th>Energy [kJ/kg]</th>
<th>$d_{25,3}$ [μm]</th>
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<td>PEF 50</td>
<td>212</td>
<td>342</td>
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Table 1: Measured reference diameters of the volume for 25%, 50% and 99% of the particles before and after the treatment.
Figure 3: Particle size measurements presented as (A) histogram and (B) sum curve of well settling sludge and (C) histogram and (D) sum curve of foam with filament organism.
The mean circularity increased by PEF treatment from 0.735 to 0.83 and the standard deviation decreased from 0.184 to 0.141, respectively. The main part of increased circularity can be seen for particle up to 20µm in Figure 4. Consequently the micro-flocs, which have been described in the beginning, seem to sharpen their boundary and the PEF treatment does not hit the compact structure, but acts upon the peripheral rim of the surface around. Due to the huge inner forces of micro-colonies [8] [18] it seems reasonable that they can not be destroyed too easily. The tails from 20µm to 200µm are having a similar outward appearance in figure 4. Probably the form and boundary effect does not led to such a clear form, as these particles are consisting of many micro-flocs and not one nucleus.

On the basis of the description of the furthermore PEF effect on cell membranes by Zimmermann et al. [19] it can be concluded, that if the PEF implementation does not have a direct effect on the structure, the perforation of the membranes reduces the resistibility. The parts of structure, which are exposed to strong forces, will no longer withstand these forces. Comparing PEF to other disintegration techniques this effect on the particle size is quite extraordinary. For ultra sonic, an already implemented disintegration technique, Lehne et al. [20] stated that the major effect for an energy input smaller than 30kJ/kg leads to a change in particle size, e.g. from 33µm to 13µm.

Comparing the change of particle structure to the release of organic compound, here presented as the amount of dissolved organic carbon per specific energy input in relation to the amount of VSS in Figure 5. Though different sludge have been taken and different the release varies mainly between 0.08%/kJ/kg) and 0.14%/kJ/kg). From this figure it can be concluded that the amount of VSS has got a minor effect on the affectivity of PEF implementation. Before comparing the affectivity of PEF implementation to other disintegration techniques given in Figure 6 some assumptions have got to be preset. In the calculated example the VSS is 33% of the SS, the release amounts 0.12%/kJ/kg), an energy input of 150kJ/kg is taken and the release of COD corresponds to DOC. Firstly a VSS of 8g/kg and secondly a VSS of 40g/kg is preset. The calculation yields the figures specific energy input of 12500 kJ/kgSS and 2500 kJ/kgSS, respectively, and a release of 18% in both cases, and can be compared to the parameters of Figure 6 by Müller [21]. For the first assumption the results demonstrate that PEF is an extremely energy consuming technique, if the SS is low. Secondly, PEF can compete to ultrasonic homogenizers (UH), but it still dissipates more energy than Stirred Ball Mills (SBM), High Pressure Homogenisers (HPH), Mechanical Jet Smash Technique (MJS), High Performance Pulse Technique (HPP) and Lysat-Centrifugal-Technique (LC). A maximal possible sludge thickening of about 60g/kgSS comes up to the state-of-the-art.

The measurement of the activity by DHA showed also a minor effect of SS content on the inactivation activity. For different sludge samples no analogue tendency was found which can be deduced to the diversity of sludge. However a minimum inactivation was found, which is marked in Figure 7. This graph may describe the least inactivation, though is is also possible to reach a higher results. An inactivation of 100% was found from 100kJ/kg to 250kJ/kg. Despite the inactivation the particle size can keep constant as shown in Table 1.
Figure 5: Released percentage of total releaseable organic carbon per energy input (\(DD_{\text{spec}}/E_{\text{spec}}\)) for different VSS contents.

Figure 6: Degree of disintegration in relation to the specific energy input for various disintegration techniques [23].

Figure 7: Inactivation rate vs. energy input \(E_{\text{spec}}\). Samples were treated with field strengths from 15kV/cm up to 19kV/cm.

Figure 8: Destroyed isolator after continuous operation. In long-run experiments the implementation was disturbed by technical problems, like the destroyed isolator. The damage of the isolator can be deduced from the reduced distance by the undercut of the seal rings. About a future implementation of PEF technique it has to be concerned that in general the staff will be reduced on modern WWTP. The staff controls the plant on monitors from a switch room. This room can be some hundreds meters away from PEF installation. In case of failure the security switch off has got to work well and the PEF plant should only be handled by skilled personal. Furthermore the maintenance time has got to be extremely low. At presence this can not be guaranteed. Further on the supply with replacement part of the switches, e.g. the spark gap, still takes too long.

CONCLUSIONS

The research of the particle size and form showed that the particle size can keep stable in case the sludge is not dominated by filament organism. In case of a huge amount filament organism, the outstanding parts can be sheared after the membrane is weakened by perforation. The floc surface is the most probable place for the cut-off as here are appearing huge shearing forces by the different velocities of the floc and the surrounding water. Further on it was found that the circularity of the particles changes for sizes up to 20µm. Floc of these sizes are described as very compact and stable micro-floc, that is why similar effects of surface cut-off as for filaments appear and finally result into more stable forms of increased circularity. Concerning the energy input PEF implementation is an energy consuming technique which affectivity can be improved by rising the SS content. For high SS contents PEF implementation could be competitive to ultrasonic homogenizers. So in any case sludge should be thickened before treatment. From the test about the inactivation of dehydrogenase activity a minimal rate of inactivation can be deduced and an inactivation of 100% will be reached at about 250kJ/kg what corresponds to an average power of 70KW at a sludge flow of 1t/h. For future installation of PEF technique on WWTP aspects of safety, security, maintenance and lifetime of power supply have to be considered.
REFERENCES


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