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Conditioning, Thickening, and Dewatering of Mechanically Disintegrated Excess Sludge

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Conditioning, Thickening, and Dewatering of Mechanically Disintegrated Excess Sludge

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ABSTRACT

The influence of mechanical disintegration of excess sewage sludge on the performance of centrifugal dewatering and filtration was investigated. Examining different methods of mechanical cell disintegration, the best results were obtained using a high-pressure homogenizer. As a result of disintegration the dry solids content of the dewatered sludge increases when applying centrifugal forces. In the case of unconditioned sludge separated by using a beaker centrifuge this can be explained by the large portion of organic components that can be found in the centrate, whereas a high degree of the inorganic components can be found in the sediment. By adding conditioning agents the organic components are flocculated while the disruption of the particle structure leads to an increase in conditioner-demand. A dual conditioning using ferric salts and polymer led to the lowest dosage and the best dewatering results. Thickening results (using a decanter) are

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improved for disintegrated sludge that may be caused by a different floc structure. Sludge flocs created from smaller sludge particles and a higher amount of flocculation agent lead to better thickening properties. Dewatering results (using a membrane plate and frame filter) were deteriorated due to the disintegration. Improved dewatering results obtained in a high-pressure filter press show a potential improvement by disintegration, but not for commercially available dewatering equipment. In industrial application disintegration shows some positive effect on thickening of excess sludge, while the dewatering results are deteriorated. The disintegration of cells presents an opportunity to reduce the waste solid, but there are still challenges to achieve effective dewatering with existing industrial technologies.

Key Words: Mechanical disintegration; Cell-disruption; Dewaterability; Excess sludge; Conditioning.

INTRODUCTION

Disintegration of sludge is a pretreatment process to improve subsequent steps of sludge handling. Chemical, physical, and biological processes can be used.[1] Applying mechanical shear and pressure forces into a sewage sludge will result in disintegration of the sludge structure. Sludge flocs as well as cell membranes of the microorganisms can be destroyed by mechanical disruption. Disintegration of sludge is used in several applications in order to reduce the sludge mass or to improve the sludge characteristics[2]:

Reduction of Sludge Mass

- Improvement of aerobic and anaerobic stabilization processes
- Reuse of sludge as carbon-source for biological nitrogen and phosphorous removal
- Improvement of settling properties
- Improvement of conditioning and dewatering

Improvement of Sludge Characteristics

- Nitrogen and phosphorous recycling possibilities
- Reduction of bulking and foaming
- Pathogen reduction

This research work concentrates on the improvement of anaerobic digestion.[3,4] One objective of the disintegration of sewage sludge is the improvement of settling and dewatering. Only a few investigations deal with this topic.[3,5] Research results are reported showing that a treatment through ultrasound improves the solids-content in the dewatered sludge by up to 5%.[5] In this case the digested sludge is disintegrated prior to conditioning. It is stated that no increase in the demand of conditioning agent is necessary. The explanation given is an optimal particle size distribution that can be attained. No statement is made on the destruction of the cell walls leading to the release of intracellular water, which can be separated mechanically when dewatering the sludge. If the disintegration of sewage sludge is executed to improve anaerobic digestion, a higher demand of polymers after the anaerobic stabilization at equal dewatering result can be expected.[3] Mechanical disintegration of sludge destroys the floc structure and increases the amount of colloidal particles. The amount of colloidal particles has a great effect on polymer-demand and dewaterability. By disintegration polysaccharides are released that have a high demand of polymers because of their negative surface charge. Polysaccharides are slowly reduced during the digestion process.

Some recent publications focus on the improvement of settling behavior of filamentous sludge.[6] By destroying the voluminous structure of sludge flocs containing filamentous bacteria it is possible to achieve settling properties of common waste-activated sludge.

Mechanical disintegration is a well-established process for obtaining intracellular products such as proteins or enzymes from biotechnological applications.[7] The disintegration methods investigated in this research work have all been proven to be suitable for breaking up microorganisms. For continuous operation stirred ball mills and high-pressure homogenizers are applied.

MATERIALS AND METHODS

The presented results were obtained in laboratory tests using excess sludge from wastewater treatment plants with 80,000 and 250,000 population equivalents. The suspended solids content amounted to 1% (SS) and the volatile suspended solids content was about 70% (VSS).

The excess sludge was disintegrated by a stirred ball mill (Netzsch, type LME 4) and a high-pressure homogenizer (APV-Gaulin, LAB 60), both with a capacity of about 50 l/h. For examination of the degree of disruption the excess sludge was treated with different operational parameters. The duration of grinding, the agitator speed and the size of the grinding beads of the stirred ball mill as well as the fluid pressure (Δp) of the high-pressure homogenizer were varied.

The degree of cell disruption or disintegration can be measured using two biochemical parameters. To determine the degree of disintegration DD_o the oxygen consumption must be measured. Then the defined specific oxygen consumption OC_d of the disintegrated sludge has to be related to the specific oxygen consumption of the untreated sludge OC_o.

$$DD_o = 1 - (OC_d/OC_o) \quad [\%] \tag{1}$$

Using the chemical oxygen demand (COD) a maximum release has to be determined by an alkali hydrolysis (COD_a). The degree of disintegration can be described by the following equation using the COD_o of the untreated and the COD_d of the disintegrated sludge (COD values were analyzed in filtrated samples):

$$DD_{COD} = (COD_d - COD_o)/(COD_a - COD_o) \quad [\%] \tag{2}$$

After mechanical treatment the excess sludge was thickened or dewatered using various methods. A beaker centrifuge (Beckmann J2-21) was used at centrifugal accelerations (a) of 1500 to 27000*g with a spin time of 10 min. A decanter with a drum length of 600 mm and a diameter of 160 mm was used at a centrifugal acceleration of 900*g and a throughput of 60 l/h. A plate and frame filter was used with plate size of 250 × 250 mm. The filtration pressure was $13{*}10^5$ N/m^2 in case the standard plates were used. With membrane plates the filtration pressure was $6{*}10^5$ N/m^2 followed by a pressure of $7{,}5{*}10^5$ N/m^2 at the membranes. Additionally a high-pressure filter[8] was used for the post-treatment of the filter cake. A sample of about 70 mm in diameter was taken from the filter cake of the plate and frame press and post dewatered by a hydraulic cylinder for 15 min at $100{*}10^5$ N/m^2.

During the experiments with the beaker centrifuge no conditioning of the sludge took place. Using the decanter and the filters conditioning was achieved using organic polymers (BC 655 and BC 55L, Stockhausen), ferric salts, or lime. An optimal conditioning (g conditioning agent/kg SS) was achieved by measuring the streaming-potential (Milton Roy, SC 4200). During this conditioning, agents were added until the isoelectric point was reached, where no electrostatic forces are affecting the particles. The dry solids content (DS) of the sludge cake was determined under deduction of the conditioning agent-mass.

EXPERIMENTS

The dewatering properties depend on the characteristics of the suspension and on the used dewatering machine, because the structure of the sewage sludge is changed significantly by the mechanical treatment. Using a beaker centrifuge fundamental knowledge of the dewatering properties of disintegrated excess sewage sludges were to be gathered. Within these experiments no conditioning agents were added, in order to not overlap the effect of the disintegration by the flocculation. For the sludge dewatering in technical scale using filters or centrifuges the conditioning is essential. As the disintegration influences the conditioning properties this topic was investigated in detail. To determine the optimum conditioning agent dosage the streaming potential was measured. A decanter was used for the thickening in the centrifugal field. For the filtration experiments a chamber filter press was employed. The investigation of the compressibility of the filter cake was carried out with a high-pressure filter.

BEAKER-CENTRIFUGE

The beaker centrifuge was used to study the behavior of disintegrated sludge. Because of the high centrifugal forces and the long spin time the results cannot be used in industrial scale using commercially available technology. When operating a beaker centrifuge at high centrifugal accelerations, sludge that has been disintegrated with a high-pressure-homogenizer shows a significant increase of the dry solids content in the sediment compared with the untreated sewage sludge. Figure 1 shows the results of treated sludge—at five different homogenizer pressures—in comparison to those of untreated sludge. It can be seen that higher contents of dry solids in the sediment (DS_S) are obtained when applying centrifugal accelerations of more than 3000*g.

The reason for this effect is the intensive disintegration of the sludge caused by the application of the high-pressure-homogenizer. The centrate contains a large portion of organic components, whereas a high degree of the inorganic components can be found in the sediment. The increase of solids content caused by the disintegration can be attributed to the fact that the ratio of the inorganic to the organic portion in the sediment increases. The correlations, which are presented in Fig. 2, can be shown by measuring the content of volatile solids in the sediment (VS_S). At centrifugal accelerations of 1,500 g the content of volatile solids is lower for the disintegrated sludges than it is for the untreated ones. Disintegration sets organic particles of small

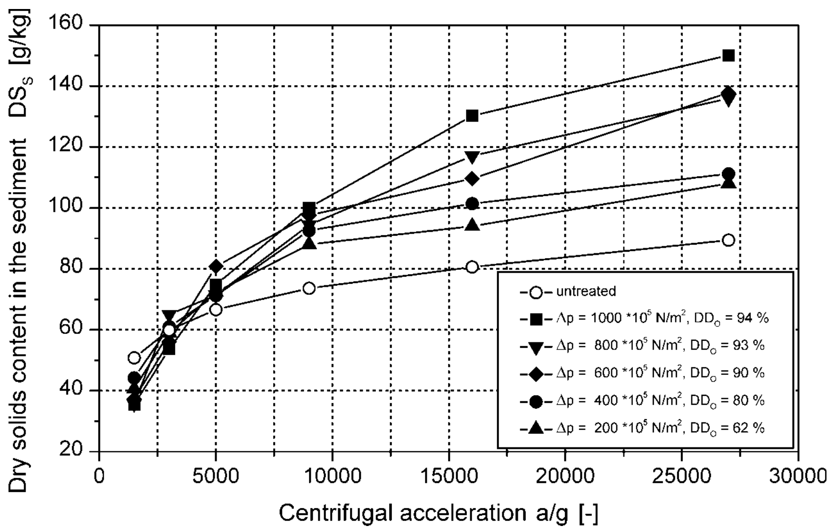

Figure 1. Content of dry solids in the sediment after disintegration in a high-pressure-homogenizer.

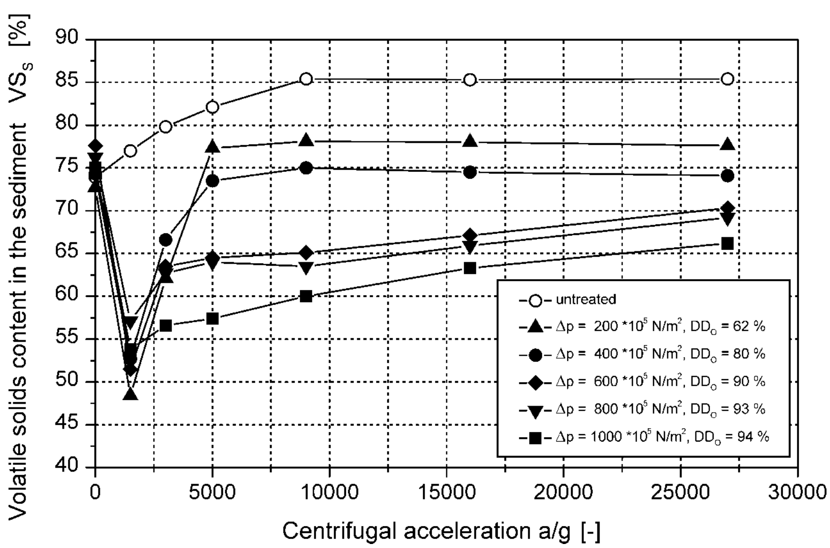

Figure 2. Amount of volatile suspended solids in the sediment after disintegration in a high-pressure-homogenizer.

diameter free, which can be separated only by higher centrifugal accelerations. The higher the degree of disintegration, the more the centrifugal forces have to be increased in order to separate the smaller particles.

Results of the suspended solids content in the centrate confirm this statement. With increasing degree of disintegration the amount of organic components that remain in the centrate—as dissolved or colloidal particles—increases. Even at high centrifugal accelerations they cannot be removed from the centrate.

The separation of organic components can be described by referring the mass of volatile solids in the sediment of the disintegrated sludge (m_{VSd}) to the one of an untreated sludge (m_{VSo}). By doing so it becomes apparent that the degree of disintegration as well as the centrifugal acceleration have an influence on the separation of the organic components. After a nearly complete disintegration at a homogenisation pressure of $1000 * 10^5\ N/m^2$, only 25 to 35% of the dry organic components are separated into the sediment, compared to the amount separated from the untreated sample (Fig. 3). This portion corresponds to the quantity of cell wall contained in the entire cell mass. It can be assumed that after a complete disintegration only the fragments of the cell wall will be separated. All the other intracellular components are completely disrupted and will remain in the centrate even at very high centrifugal accelerations.

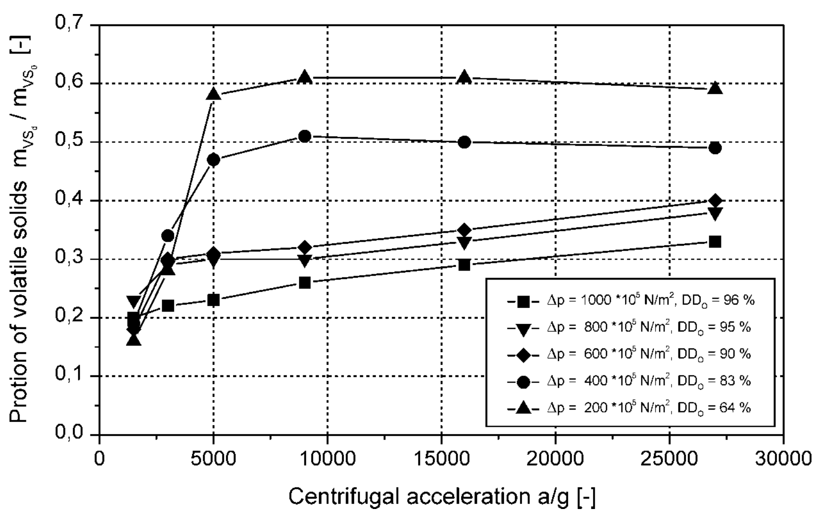

Figure 3. Portion of the separated volatile solids content in the sediment after disintegration.

The disintegration leads to a theoretical separateability of the intracellular water. Calculations have shown that the portion of water that is attached to the organic components is not influenced by the disintegration.[9] The dewatering performance is thereby defined by the portion of organic components in the dry solids, which have to be separated. A high content of dry solids in the sediment can be achieved by a low portion of organic components.

Disintegration with the stirred ball mill leads to a slight increase of the dry solids content in the sediment after dewatering in the beaker centrifuge. This is mainly a result of the abrasion of the grinding beads. Although this abrasion was subtracted from the measured dry solids content it increases the density of the separated particle-agglomerates, thus influencing the sedimentation properties and causing a compression of the sediment.

SLUDGE CONDITIONING

To achieve a high content of dry solids in the sediment during sludge dewatering, sludge conditioning has to be realized beforehand. Prior to the investigations concerning the influence of disintegration on dewaterability in technical machines, conditioning had to be optimized in several experiments.

Conditioning of disintegrated excess sewage sludge requires an increase in specific conditioning agent dose from 10 up to 15 to 20 grams per kilogram dry mass. Disintegration produces many fine particles, and large amounts of conditioner are necessary to neutralize the surface charge. Using a combined conditioning with ferric chloride sulphate ($FeClSO_4$) and a cationic polymer, the excess consumption of conditioning agent caused by the disintegration could be reduced. This combined conditioning leads to the best dewatering results with all the investigated machines. Measuring the streaming potential the optimum amount of conditioner could easily be detected for disintegrated and untreated sludges. First the amount of ferric chloride sulphate to achieve charge neutralization was determined. Then only 20% of this amount was added to a new sample, and polymer was added until charge neutralization was achieved. This method led to mass ratio polymer/ferric salt of around 0.4.

Disintegration must not lead to an increase in polymer demand. This can be shown by a preshearing using for example a shear-gap-homogeniser (disperser), with which a digested sludge was treated at 8000 rpm for 1 minute. The conditioning and postshearing was carried out with a blade type stirrer at 600 rpm. The sludge was conditioned using polymer and then dewatered using a beaker centrifuge at 1000*g for 5 min. In Fig. 4 the achieved solid content in the sediment is shown over the mixing time in the jar. The sludge pretreated in the disperser achieves the best dewatering result in case of a short mixing

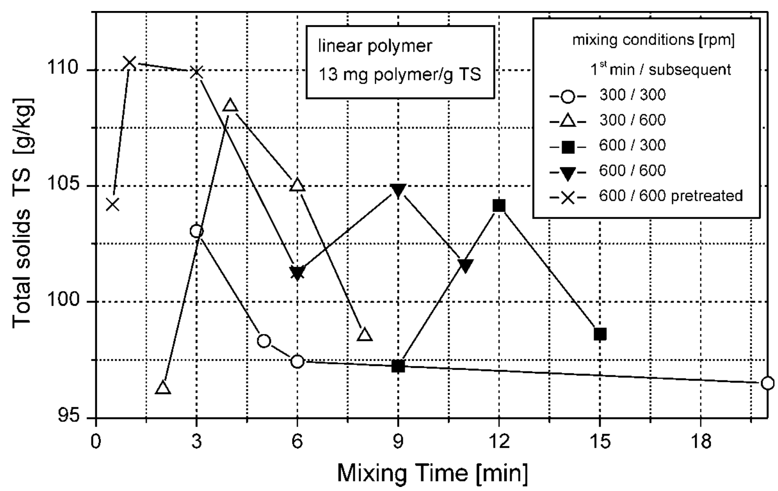

Figure 4. Solid content in the sediment after centrifugation in a beaker centrifuge.

period. For the sludges not treated with the disperser the dewatering result also strongly depends on the appropriate amount of mixing during conditioning. Therefore optimal polymer dosing is a function of the sludge properties and the conditioning parameters.

The position of the optimum concerning the mixing time is of special interest here. The peak values for TS in the sediment should not be overrated, because the conditions during the separation in a beaker centrifuge can only be applied to a limited extend to the dewatering in a solid-bowl-centrifuge or other industrial dewatering equipment.

THICKENING DECANTER

Thickening experiments in the centrifugal field could be carried out with a bench-scale decanter. Despite the fact that conditioning agent was now used with the decanter while none was used with the beaker centrifuge the results were quite similar. After disintegration with a high-pressure-homogenizer the dry solids content in the sediment could be increased by 9% for the untreated sludge to more than 12% for the treated sludge (Fig. 5). A linear correlation between the solids content and the degree of disintegration could be observed. In contrast to the experiments with the beaker centrifuge even the organic particles were separated from the centrate into the sediment by

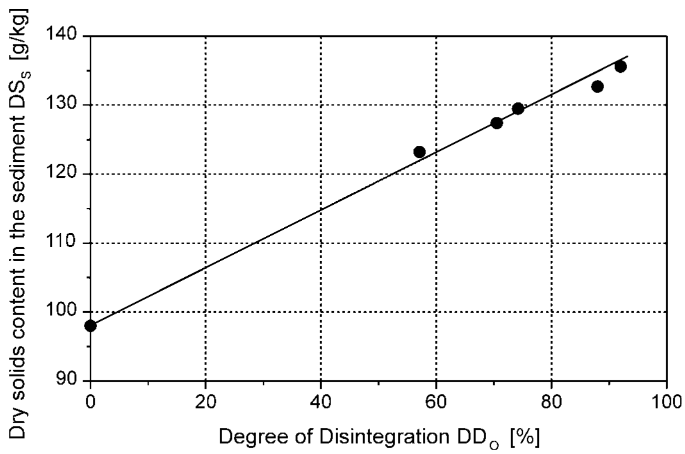

Figure 5. Correlation between the degree of disintegration after high-pressure-homogenization and the dry solids content in the sediment of the decanter.

conditioning agents. Whether the increase of the dry solids content is due to the release of the intracellular components cannot be ascertained, because the sediment still has a high water content of more than 80%. Most likely the combination of a high number of small particles and the high dose of conditioning agent lead to flocs with improved dehydration behavior.

Investigations with excess sewage sludges from different wastewater purification plants confirm the observed improvement of the solid content of the sediment caused by disintegration with a high-pressure-homogenizer. The excess consumption of conditioning agent for the disintegrated sludges was around 50 to 100% of the one for untreated sludge, if the mixing conditions were kept constant.

PLATE AND FRAME FILTER AND PRESS FILTRATION

The improvement of dewaterability that was observed when using a lab-scale filter could not be confirmed in experiments with a plate and frame filter. As a result of disintegration a decline of the dry solids content in the filter cake from 20.5% for the untreated sludge down to 14.5% for the disintegrated sludge was measured. Nevertheless the achieved content of dry components is quite good for excess sewage sludge. One reason was the application of a membrane plate, by which the dry solids content was increased from 18% for the conventional plate to 20.5% for the membrane type plate. Another reason was the combined conditioning with ferric chloride sulphate and a polymer. Because of the poor results of disintegrated sludges, further investigations concentrated on the post-treatment of the filter cake using a high-pressure-filter.

Then the pre-dewatered sludge from the chamber-filter-press was pressed for 15 min. at a pressure of up to $100*10^5\,N/m^2$. Results are described in Fig. 6. The possible pressure is influenced by the choice of the conditioning agent. In exceeding the shear strength of the cake a breaking-through of solid components occurs. The pure polymer conditioning allows only a relatively low pressure of $12*10^5\,N/m^2$ because the polymer flocs are of poor stability. Even though the flocs are of great compressibility, only a negligible increase in dry solids content can be measured because the gel-like flocs quickly block the filter medium. Consequently the permeability of the filter cake decreases and a further flow of filtrate is inhibited.

Conditioning with ferric chloride sulphate makes the application of higher pressures possible, because of the increased strength of the flocs, but at pressures above $50*10^5\,N/m^2$ a breaking-through of solid components occurred again. Because of the great strength of the flocs the compressibility of the cake was low and only a marginal increase in dry solids content could be observed.

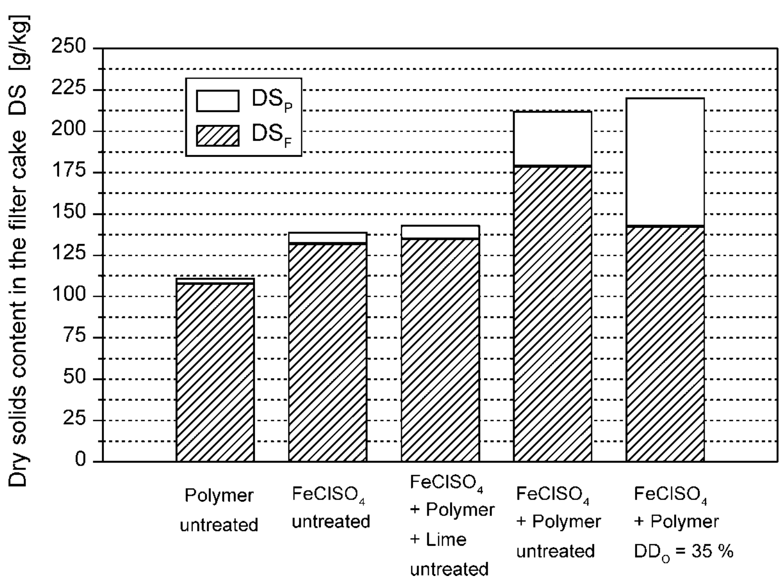

Figure 6. Dry solids content in the filter cake after filtration (DS_F) and following press-filtration (DS_P).

The compression behavior could be optimized by the combined conditioning with ferric chloride sulphate and a polymer. First of all the inorganic conditioning agent produces small, pressure-resistant agglomerates, which prevent the premature blocking of the filter. The polymer cross-links the agglomerates to bigger flocs, which cannot break through. Combined flocculation allows pressures of $100*10^5\,N/m^2$. The dosage of lime lowers the compressibility because of the enlarged portion of inorganic and stable components.

As a result of disintegration the compressibility of the sludge at a pressure of $100*10^5\,N/m^2$ increases significantly compared to the untreated sludge. Because the untreated sludge does have a better pre-dewatering performance than the disintegrated sludge the results are nearly the same at the end.

The achieved dry solids content of the press-filter-cake had a maximum of 220 g DS/kg. Together with the conditioning agent the measured dry solids content had a maximum of 260 g DS/kg or 26% DS. That proves clearly that the press-cake still consists mainly of water. The separateability of the intracellular water can only have a positive effect on the obtained dry solids content, if an extensive dewatering of the sludge has taken place. As long as the sediment-structure still consists of a large amount of water bound to the organic components, the release of intracellular water seems to have very limited benefits.

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