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DISINTEGRATION OF SEWAGE SLUDGES AND INFLUENCE ON ANAEROBIC DIGESTION

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ABSTRACT

The improvement of anaerobic digestion was investigated in an interdisciplinary research group. Using four different methods of mechanical cell disintegration the influence of the degree of disintegration and the digestion parameters on the performance of the anaerobic process was investigated. Analytical methods to describe the degree of cell-disruption had to be developed. The best results were obtained using a stirred ball mill and a high-pressure homogenizer. As a result of disintegration the degradation is accelerated and the digestion time can be reduced, especially when using immobilized micro-organisms. The treatment of digested sludge by ozonization respectively by mechanical disintegration led to an improved biodegradability of residual organic compounds. In a following second anaerobic process the treated sludge reached an even higher degree of degradation. On the other hand the disruption of the particle structure leads to an increase in polymer-demand and no improvement in dewatering results. Sludge water, returned to the aeration tanks, is slightly more polluted, especially the concentration of ammonia increases because of the better anaerobic digestion. © 1998 IAWQ Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Anaerobic digestion; biodegradability; cell-disruption; dewaterability; excess sludge; mechanical disintegration; ozonization; pollution of sludge water; polymer-demand; residual sludge components.

INTRODUCTION

A common method for the degradation of excess sludge is biological treatment by anaerobic processes. Even after some decades of optimisation a retention time of more than 20 days and the construction of huge digesters is usually necessary for degradation in an anaerobic process. Nevertheless the highest degrees of degradation reached, amounted to about 40% for excess sludges at the most (Kapp, 1984).

There are several causes for these poor results. The hydrolysis of the particulate organics limits the speed of the process, the facultative anaerobic micro-organisms are not affected in an anaerobic degradation process and some of the organic matter is not bioavailable (Roediger *et al.*, 1990; Kunz, 1992).

In order to improve the performance of the anaerobic degradation process, mechanical disintegration was investigated as an innovative process step in the sequence of sewage sludge treatment. The objective is to accelerate the digestion of sewage sludge, to raise the degree of degradation and thus to decrease the amount of sludge to be disposed. Similar investigations are carried out by several researchers (Tiehm *et al.* (1997), Dohanyos *et al.* (1997), Baier *et al.* (1997), Choi *et al.* (1997)).

Fundamental experiments on mechanical disintegration of sewage sludge were carried out by Kunz (1992) and Müller and Schwedes (1992). The excellent results led to the foundation of an interdisciplinary co-operation project involving four institutes of the Technical University of Braunschweig. The objective of this project is to thoroughly describe the influences of disintegration on sludge- and wastewater-treatment (Fig. 1).

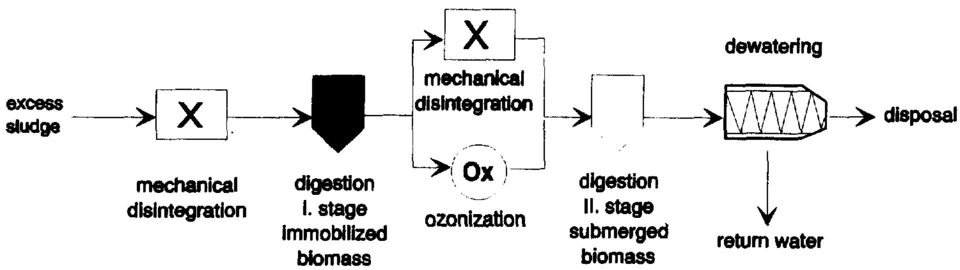

Figure 1. Sludge treatment process including the mechanical disintegration.

Excess sludge consists mainly of micro-organisms. The hydrolysis of the cell-walls of the bacteria limits the degradation process. By applying mechanical disruption the break-up of cells occurs in minutes instead of days. The intracellular components are set free and are immediately available for biological degradation which leads to an acceleration of the process. Facultative anaerobic micro-organisms are disrupted as well and become degradable, thus resulting in a higher degree of degradation.

Mechanical disintegration is a well known process to obtain intracellular products such as proteins or enzymes in biotechnological applications (Schwedes and Bunge, 1992). The disintegration methods investigated in this research work, have all been proven to be suitable for breaking up micro-organisms. For continuous operation stirred ball mills and high-pressure homogenizers are applied. Based on investigations of the disintegration of yeast and bacteria (Bunge, 1991) the influence of mechanical disintegration on characteristics and digestibility of sewage sludge has been shown in this research work over the last six years (Müller, 1996).

A further improvement of the anaerobic degradation process can be achieved by a two-stage process and the immobilisation of biomass. Using a two-stage process the complex demands of the different types of bacteria involved can be optimised in separate steps (Dichtl, 1984). In order to realise short digestion times the retention of the slowly growing anaerobic micro-organisms is necessary. This can be done by using fixed beds for the immobilisation of the active bacteria (Müller *et al.*, 1996).

The degree of biodegradability of the organic matter can be raised with the help of partial oxidation of digested sludge with ozone (Krull *et al.*, 1996). The idea is to apply additional treatment methods to these refractory sludge components, which could not be disintegrated in either the one-stage or the two-stage anaerobic degradation process. The refractory sludge components will then be partially oxidised either with ozone, or with ozone in combination with hydrogen peroxide and will afterwards be further minimised by biological treatment.

Microbiological characterisation is necessary for an optimised anaerobic degradation. In order to describe the influences of mechanical disintegration on bacteria in excess sludge and to describe the subsequent anaerobic treatment, the analysis of the structure of microorganism-biocenosis is important. The results obtained by these investigations make it possible to determine the ideal operating conditions, which are necessary for minimising the organic part of the generated sewage sludge - to be disposed of in the end - and for optimising the mineralization process.

The dewatering characteristics of sludge can be described by parameters such as particle size distribution, amount of colloidal particles, surface charge and volatile suspended solids. The mechanical disintegration of sludge destroys the floc structure and increases the amount of colloidal particles (Kopp *et al.*, 1997). The amount of colloidal particles has a great effect on polymer-demand and dewaterability (Roth, 1991; Kopp and Dichtl, 1996).

The influence of the return flow of sludge water is significant for the operation of sewage treatment plants. The disintegration increases the concentration of dissolved and colloidal substances. The improved digestion of disintegrated sludges leads to higher pollution of the sludge water especially with TKN.

MATERIALS AND METHODS

The presented results were obtained in laboratory tests using excess sludge from wastewater treatment plants with 70000 and 120000 population equivalents. The suspended solid content amounted to 1-4% (SS), the volatile suspended solids were about 70% (VSS) and the sludge ages were 3 and 13 days.

The excess sludge was disintegrated by a stirred ball mill (Netzsch, LME 4), a high-pressure homogenizer (APV-Gaulin, LAB 60), an ultrasonic homogenizer (B. Braun, Labsonic L) and a shear-gap homogenizer (IKA, Ultra Turrax T25). 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 (SBM), the fluid pressure of the high-pressure homogenizer (HPH) and the duration of treatment in the ultrasonic homogenizer (UH) and in the shear-gap homogenizer (SH) were varied.

The particle size distribution was measured using a laser diffraction instrument (Sympatec, Helos). The degree of cell disruption can be measured using two biochemical parameters. The rate of oxygen demand and the COD release have been proven to be suitable which was confirmed by pictures taken with an electron microscope. To determine the degree of disintegration DR_0 by the oxygen consumption, the measured specific oxygen consumption OC_m has to be related to the specific oxygen consumption of the untreated sludge OC_u.

$$DR_0 = 1 - (OC_m/OC_u) \qquad [\%] \qquad (1)$$

Using the chemical oxygen demand (COD) a maximum release has to be determined by an alkalic total fusion process (COD_a). The degree of disintegration can be described by the following equation using the COD_u of the untreated and the COD_m of the treated sludge (COD values were analysed in filtrated samples):

$$DR_{COD} = (COD_m - COD_u) / (COD_a - COD_u) \qquad [\%] \qquad (2)$$

After mechanical treatment the excess sludge was digested in lab-scale 20-litre anaerobic reactors. The reactors were operated in continuous flow experiments. A two stage process was used for the investigations. The digestion time (t_d) varied between 2-17 days at a temperature of 35°C. The first stage (t_d = 2d-7d) was equipped with a vertical bed material in order to immobilize the anaerobic biomass, the second stage (t_d = 10d) used suspended micro-organisms.

For the ozone treatment ozone was generated by silent discharge. An ozone entrance concentration of approximately 100 mg/l was used for the experiments. A bubble column of 2.5 litres was used as an oxidation reactor. Foam development was suppressed by a mechanical foam destroyer. During the experiments the ozone concentration and the gas volume flow rate was determined photometrically in a flow-through-type cell at a wave length of $\lambda = 254$ nm at the in- and outlet of the reactor.

An optimal flocculation (polymer-demand g/kg SS) was achieved when no electrostatic forces affected the particles at a zetapotential in the centrate between -3mV to ± 0mV. The zetapotential was measured electrophoretically in the centrate which was diluted to 0.5 mS/cm conductivity (Malvern, Zetamaster).

Subsequently the conditioned sludge was dewatered for 5 min in a lab-scale beaker centrifuge (Heraeus, Labofuge A) at 3000 rpm (z = 900 g). Apart from the suspended solids content of the sludge cake ($SS_{dewat.}$), the COD, TKN and phosphate content in the centrate were determined.

RESULTS AND DISCUSSION

The influence of mechanical disintegration and ozonization of excess sludge on digestion process, particle size distribution, conditioning, dewatering and pollution of sludge water is demonstrated in the following points:

- mechanical disintegration of excess sludge
- digestion of disintegrated excess sludges
- ozonization of anaerobic sludges
- digestion of ozonizated or disintegrated anaerobic sludges
- dewatering of disintegrated and digested sludges.

Mechanical disintegration of excess sludge

Parameter-studies have been carried out using a stirred ball mill, a high-pressure homogenizer, an ultrasonic homogenizer and a shear-gap homogenizer. The performance of the various disintegration methods can be compared with each other using the specific energy, which is defined as the amount of mechanical energy that stresses a certain amount of sludge. A suitable method to describe the effectiveness of a comminution process is provided by measuring the particle size distribution. Even for short grinding times and correspondingly low energy input, significant reduction of the mean particle size and an increase in surface area of the sludge could be observed, because the floc structure of the sludge had been destroyed.

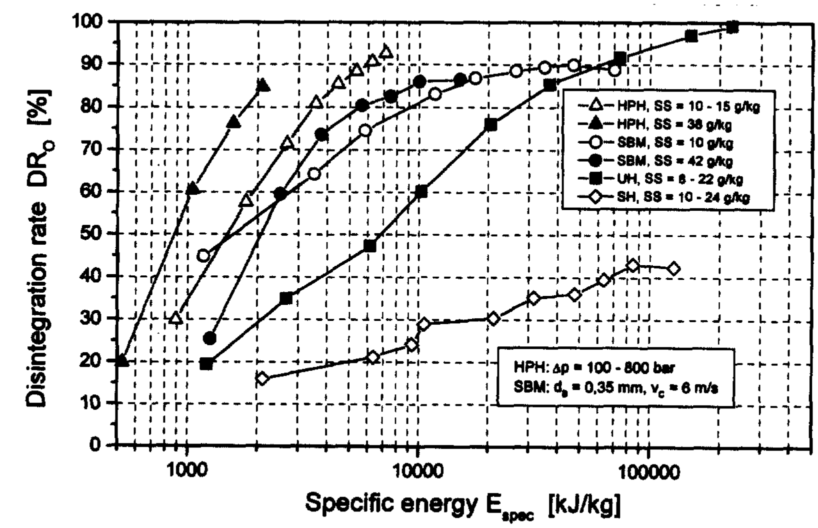

Figure 2. Degree of disintegration (DR_O) as a function of specific energy for different disintegration methods.

The measurement of particle size distribution is an appropriate method to describe the change in sludge structure but the disruption of cells can not be properly determined. The degree of cell disruption can be measured using biochemical parameters like the rate of oxygen demand and the COD release. High degrees of cell disruption were obtained with all investigated methods, except when using the shear-gap homogenizer (Fig. 2). Considering power consumption the high-pressure homogenizer and the stirred ball mill are the most economic disintegration aggregates. The best results can be obtained when using the stirred ball mill for long grinding times, at high agitator speeds and with small particle sizes of the grinding beads. In order to obtain comparable results with the ultrasonic homogenizer a relatively high amount of energy is consumed, but one has to consider that this machine was not designed for continuous process operation.

The extent of cell disruption does not only depend on the operational parameters of the disintegration machines but also on the suspended solids (SS) content. By increasing the SS content of the sludge up to 5% a degree of disintegration of more than 60% can be reached at a specific energy input of approx. 1000 kJ/kg SS.

Digestion of disintegrated sludges

A two-stage process was used for the investigations. Treatment results of sludges from two different wastewater treatment plants are presented. For both types of sludge the mechanical disintegration accelerated the biological degradation of the sludge (Fig. 3). The specific production of digester gas and the degradation of organic substances were significantly raised. The degree of degradation is between 10 and 20% higher in comparison to the untreated sludge.

The sludge with a higher sludge age reached a lower degree of degradation. During the long retention time of the sludge in the aerobic process a further degradation of the organic matter took place, since the removal of ammonium requires a high sludge age because of the slow-growing nitrifying bacteria.

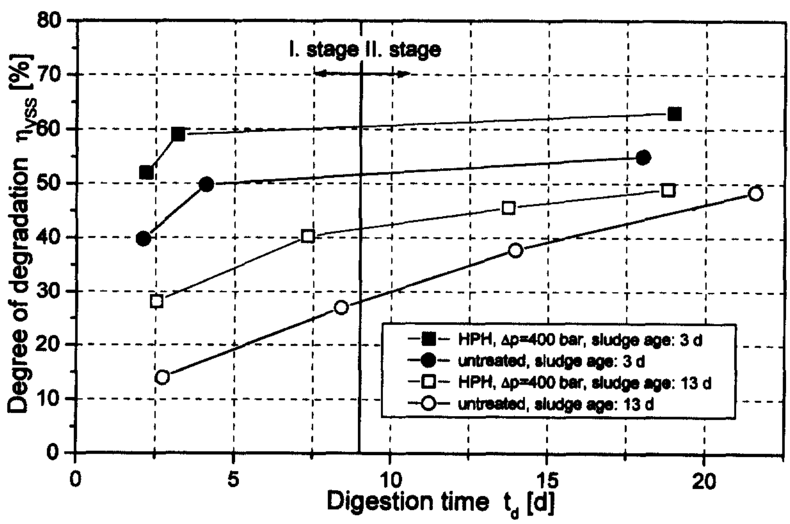

Figure 3. Degree of degradation of organic matter as a function of digestion.

Ozonization of anaerobic sludges

Several experiments were carried out to investigate the change in sludge composition during partial ozonization. Figure 4 shows the decrease of organic matter and the concentration of polysaccharides and proteins in the solid phase as a result of the ozone treatment. By ozonization about 60% of the organics, 64% of the polysaccharides and around 90% of the proteins can be liquidized. The liquidized organic matter can be fully regained in the liquid phase of the suspension.

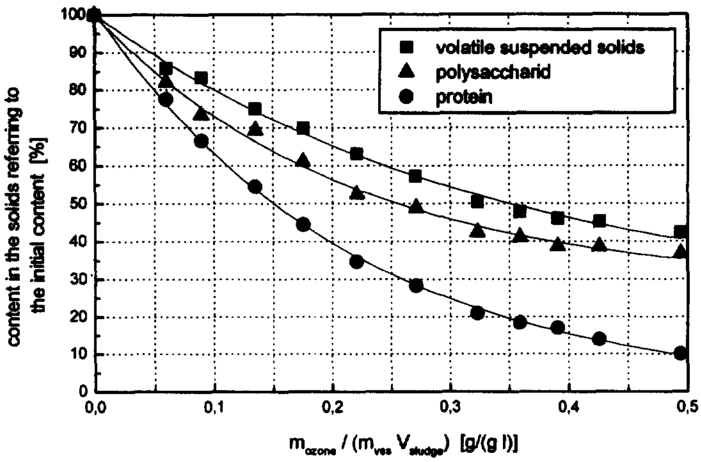

Figure 4. Influence of ozone treatment on the composition of anaerobic sludge.

Digestion of ozonized or disintegrated anaerobic sludges

Using a two-stage process a further improvement of the degradation result was obtained by an additional treatment in between the stages. In the first stage, after a digestion time of 5 days, the anaerobic sludge was disintegrated in a high-pressure-homogenizer or was partially oxidized by ozonization. After the treatment the sludges were anaerobically digested in the second stage for another 10 days. These sludges degraded to a higher degree compared to untreated sludge (Fig. 5). The degree of degradation correlates to the degree of disintegration, measured by the chemical oxygen demand. It seems to be of no influence whether the disintegration was carried out by mechanical or chemical methods.

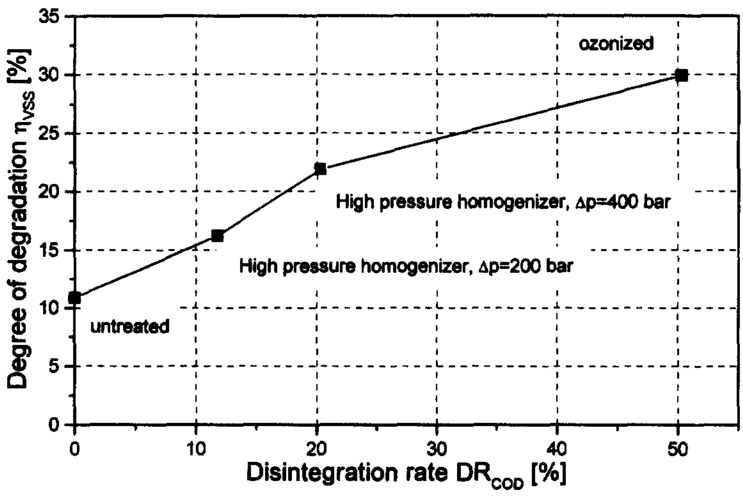

Figure 5. Influence of disintegration on the degradation of anaerobic sludges.

Dewatering of disintegrated and digested sludges

Various conditioning and dewatering tests were carried out accompanying the investigations of the degradability of the sludges. The results of these tests are compared in Figure 6 showing untreated sludge

(DR_0 = 0%), wet milled sludge (DR_0 = 43%) and two homogenized sludges (DR_0 = 25% resp. 40%) with a sludge age of 13 days.

The organic matter is further reduced with rising digestion time and thus the density of the particles increases. Experiments carried out with a sludge of 3 days sludge age showed that better dewatering results could be obtained with the disintegrated sludges (Kopp *et al.*, 1997). Nevertheless for the sludge of 13 days sludge age the suspended solids content of the sludge cake, after being dewatered in a centrifuge, decreases with rising digestion time. Higher degrees of disintegration lead to poorer dewatering results. At the end of the second stage (t_d = 17 d) all samples show the same suspended solids content after dewatering.

The polymer demand increases as a result of disintegration. Because of the subsequent anaerobic degradation a significant reduction of the polymer demand can be registered, but is still twice as high for the disintegrated sludge as for the untreated sludge. Even with long digestion times the polymer demand is not reduced (Fig. 6). A reduction of polymer demand by multi-step flocculation is investigated.

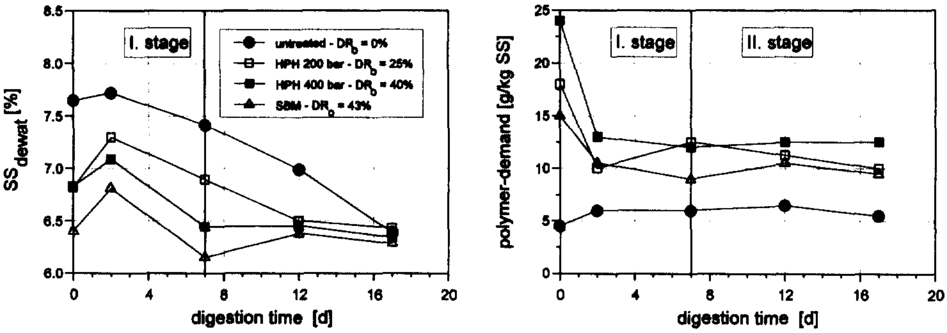

Figure 6. Dewatering results and polymer demand in dependence of digestion time.

The disintegrated anaerobic sludges showed an improved dewatering result after the second anaerobic digestion process of 10 days. The suspended solids content rose to 7.5% without the necessity of a higher polymer addition.

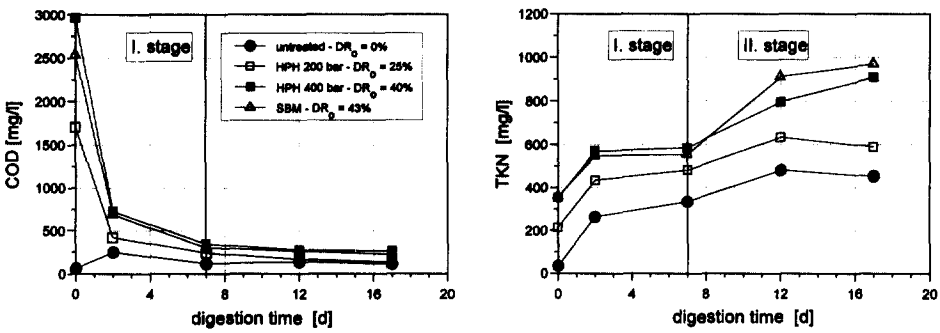

Figure 7. Pollution of sludge water in dependence on the digestion time.

In Figure 7 the pollution of sludge water independent of digestion time is shown. The degree of degradation of released cell contents is high. After a digestion time of more than two days the COD concentrations of the disintegrated samples were almost at the same level as the ones of the untreated samples. Carbon compounds set free by disintegration are degraded during digestion. Because of better anaerobic digestion of the sludge, especially protein degradation, the concentration of ammonia increased. As a result of this, the mean value of the return flow of TKN is about 20 to 30% higher than usual. The proportion carbon/nitrogen

($CSB_{filtred}/TKN$) which is important for the biological treatment of sludge water, remains unchanged by the disintegration. Phosphate was precipitated with cations (Mg^{2+}, Ca^{2+}) and the concentration decreased with digestion time.

New investigations on the reuse of disintegrated sludges as a carbon-source for the denitrification process were carried out by Kunz and Wagner (1994) and Yasui *et al.* (1996).

CONCLUSIONS

The mechanical disintegration of sewage sludge destroys the floc structure of sludge and disrupts the cell walls of the micro-organisms. State of the art science and technology high-pressure homogenizers and stirred ball mills are more effective than ultrasonic homogenizers. The specific energy consumption for disintegration can be minimised using a high suspended solids content.

As a result of disintegration the degree of anaerobic degradation is higher and the digestion time can be reduced, especially if fixed-bed reactors are used. An anaerobic process with retention times down to 4 days and a high sludge loading rate can be realised. This reduces the digester volume needed and therefore construction costs as well.

The disintegration leads to a higher degree of degradation, a higher gas production and a reduction of the sludge to be disposed. The two-stage anaerobic process in combination with disintegration of anaerobic sludge has been proven appropriate for achieving the highest possible degree of degradation. Either a mechanical disintegration or a partial oxidation using ozone can be applied prior to the second anaerobic treatment.

The dewatering results of the anaerobic sludge are not significantly affected by the disintegration. The increase of polymer-demand, caused by the increase in surface area, has to be considered as a disadvantage. The return flow of nitrogen compounds rises, because ammonia is produced in the anaerobic digestion of proteins.

A rough calculation of energy-consumption and costs shows, that this process can be realised economically (Dichtl, 1996). The surplus gas can be used in gas machines. This energy-yield is of the same order as the energy which is needed for the mechanical disintegration. The investment for the disintegration aggregates has to be seen in relation to the reduced digester volume needed. The reduced costs for the sludge disposal will lead to a practical use of this new technology.

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LIST OF INDICEES AND SYMBOLS

a		alkaline total fusion
m		mechanical treated sample
u		untreated sample
Δp	bar	pressure
h_{VSS}	%	degree of anaerobic degradation
COD	-	chemical oxygen demand
d_B	mm	bead diameter
DR	%	degree of disruption
DR_{COD}	%	DR measured by COD release
DR_0	%	DR measured by oxygen consumption

E_{spec}	kJ/kg	specific energy for disintegration
m_{ozone}	kg	mass of ozone
m_{VSS}	kg	mass of volatile suspended solids
HPH	-	high-pressure homogenizer
OC	mg/l.min	oxygen consumption
SBM	-	stirred ball mill
SH	-	shear-gap homogenizer
$SS_{dewat.}$	%	dried matter of sludge cake
t_d	d	digestion time
TKN	-	Kjeldahl nitrogen concentration
UH	-	ultrasonic homogenizer
v_c	m/s	velocity circumferential
z	g	centrifuge units

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