Project Decamax
Work Package 2:
Results of pilot-scale dewatering trials performed in Braunschweig

Assessment of various operational factors on centrifugation performances

Dipl.-Ing. Karsten Fülling
Dipl.-Geoecol. Daniel Klein
Prof. Dr.-Ing. Norbert Dichtl

Prof. Dr.-Ing. Norbert Dichtl
Technische Universität Braunschweig
Pockelsstr. 2a, 38106 Braunschweig, Germany
Tel. +49 (0) 531 391-7936, Fax +49 (0) 531 391-7947
www.tu-braunschweig.de/isww

Imprint:

Decamax:

Report on the Optimisation of centrifuge dewatering process in Wastewater Treatment Schemes – Pilot Trials

Authors:

Norbert Dichtl, ISWW

Daniel Klein, ISWW

Karsten Fülling, ISWW

Reviewers:

Boris Lesjean, KWB

Julia Kopp, KBK

Christoph Siemers, SE|BS

Braunschweig, March 2014

Research report within the framework of the project Decamax, written by the Institute of Sanitary and Environmental Engineering, Technische Universität Braunschweig.

Decamax is a project of and coordinated by KompetenzZentrum Wasser Berlin (KWB). The project is supported financially by Veolia Eau and Berliner Wasserbetriebe (BWB). Further project partners: Stadtentwässerung Braunschweig (SE/BS) and Kläranlagenberatung Kopp (KBK).

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1 Introduction

Sludge treatment and disposal is one of the key positions of operating costs in large wastewater treatment plants (WWTPs). On large WWTPs, dewatering of digested sludge is mainly performed with centrifuges. The performance of the centrifuge and thus, the (cost-)efficiency of the whole sludge dewatering process, strongly depends on the operating parameters of the centrifuge and the properties/preparation and dosage of the polymer used as flocculation aid.

The research project “Decamax” therefore mainly focuses on these aspects and their impact on the dewatering result, i.e. mainly the dry solid content of the sludge cake and the quality of the sludge liquor. Moreover, the impact of sludge pre-heating on sludge dewatering is assessed, because it is known that the dewatering temperature has a high influence on the process as well. Besides a technical study (Work Package 3) and full-scale trials at a WWTP in Berlin (WP 1), the project included trials with a 0.4 m^3/h pilot-scale centrifugation unit in Braunschweig (Work Package 2). The results of this work package (performed by the Institute of Sanitary and Environmental Engineering, Technische Universität Braunschweig (ISWW)) are summarised in this report.

Besides the ISWW, the pilot-scale trials were supported and evaluated by the Stadtentwässerung Braunschweig (SE|BS), the KompetenzZentrum Wasser Berlin (KWB) – also responsible for the overall project management and control – and Kläranlagenberatung Kopp (KBK). Moreover, the Decamax project team and technical committee include the Berliner Wasserbetriebe (BWB) and Veolia Wasser.

The project is financially supported by Veolia Water and BWB.

2 Research program of pilot-scale trials

2.1 Description of the pilot plant

Centrifuges operate on the basis of a mechanically induced gravity field. The differences of density between the solids and the sludge liquor lead to the phase separation. The gravity field which leads to the liquid/solid separation is achieved by a horizontally orientated drum revolving around a longitudinal axle. Solid bowl centrifuges, also known as decanters, are most commonly used for sludge dewatering. The polymer-conditioned sludge is introduced through the feeder into the rotating centrifuge drum. The spiral conveyor transports the solids sedimented on the drum walls towards the cone. For the operation to work, the spiral has to revolve faster than the drum by a certain ratio, the so called difference ratio or – as in the following report – speed difference. This ratio is controlled by the torque of the drum.

The trials described in the following report were performed with a pilot-scale decanter with a max. hydraulic throughput of 400 L/h (sum of sludge and polymer) Hiller DP 15-422 (see Figure 2-1). The main technical parameters are given in Table 2-1.

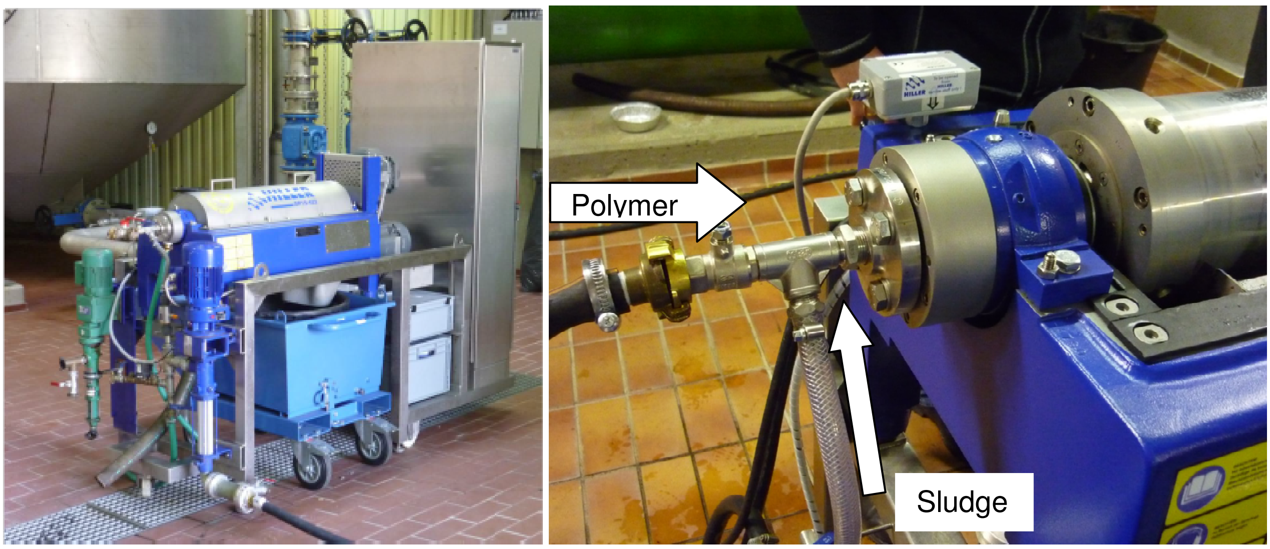


Figure 2-1: The pilot-scale decanter (left) and close-up view of the sludge- and polymer inlet (right)

Table 2-1: Properties of the pilot-scale decanter

Bowl diameter	153 mm	Conus angle	10°
Ratio diameter/length	1 : 4.22	Length of cylinder	439 mm
Max. rotational speed	6,000 rpm	Relative centrifugal force (RCF)	max. 3,080xg

The rotational speed and thus, the RCF can be controlled by a control panel, as well as the hydraulic load and the speed difference. For the first series of trials, the latter could only be changed in whole numbers (e.g. 1.0 or 2.0). For the further trials, it was possible to change the speed difference in steps of 0.1.

Polymer dosage was done by a separate progressive cavity pump fed by a polymer preparation unit. During standard operation, polymer and sludge were mixed shortly before entering the decanter (see Figure 2-1). The quantity of polymer solution added could be varied from 42 L/h to 420 L/h.

2.2 Program of the experimental series

The pilot-scale trials were divided in “blocks”, mainly focussing on the following aspects:

- Block 1: Evaluation of the influence of operating parameters such as:
    - Throughput
    - Drum speed (RCF)
    - Speed difference
    - Inner diameter of weirs

- Block 2: Impact of polymer properties and dosage:
    - Concentration of polymer solution
    - Contact time (point of dosage) of polymer
    - Effects of under- and overdosing

- Block 3: Impact of sludge pre-heating:
    - Thermo- and mesophilic digested sludge
    - Excess sludge
    - Primary sludge

Since operating- and other parameters influence each other, the division of the trials into three “closed” blocks has not been that strict. Depending on the specific trial and the performance of the sludge dewatering, operating parameters have also been varied during block 2 and 3, in order to optimise the dewatering process (See also chapter 3.5). In some cases, changing polymer properties have also been evaluated during block 1 and 3. Generally, the trials focused on an overall screening.

During one day of pilot-scale decanter operation, 4-6 different sets of parameters (settings) could be evaluated. To assess the dewatering performance of a specific setting, the relevant sludge streams and the sludge liquor (centrate) have been analysed according to the following routine program (Table 2-2).

Table 2-2: Routine sampling and analyses

Stream/Sampling point	Main parameters	Additional parameters
Digested sludge (input)	TS, TSS, LOI	Conductivity, pH, temperature
Centrate	TS, TSS	Conductivity, pH, temperature
Sludge cake (dewatered)	TS, LOI	temperature
Polymer	TS	Conductivity, pH, temperature

These routine analyses that are essential for the evaluation of the dewatering performance have been completed by optional analyses of CSB, TKN, NH_4-N, total-P and PO_4-P. Using TS and TSS of the different fractions, the separation ratio (SR) of solids was calculated.

Remark: For full-scale dewatering, only a SR of >95% is usually considered as acceptable. In the following report, the TS of sludge cake are given including decimal numbers, but differences of <1% can only be regarded as a (slight) tendency.

Additionally to these analyses, the optimal polymer dosage and the performance of a new polymer has been verified occasionally by lab-scale dripping tests and other lab-scale methods. Analyses of EPS were performed in order to evaluate the influence of sludge preheating on the EPS-, protein- and polysaccharide-content of the sludge.

2.3 Properties of the used sludges and polymers

Since the WWTP of Braunschweig (KWS) operates a thermophilic sludge digestion, most trials have been performed with thermophilic digested sludge. Mesophilic digested sludge of the WWTP Salzgitter-Nord has been evaluated within the context of the pre-heating trials, as well as primary and excess sludges of the KWS. The main properties of the sludges are given in Table 2-3.

Table 2-3: Properties of the sludges used during the pilot-scale trials

Parameter	Themophilic (KWS)	Mesophilic (SZ-Nord)	Primary sludge (KWS)	Excess sludge (KWS)
TS [%]	2.2-2.5	3.5-4.0	4.0	4.4
LOI [%]	64-67	53-57	76-80	76-78
Approx. polymer demand [kg ai/t TS]	20*	13	7	7

*comparably high due to bio-P-elimination

During the trials, two different polymers have been used. The standard polymer at KWS is the granular polymer Polysepar® PK35H that has also been used for the pilot trials at the beginning. Since it turned out to be not suitable for the given conditions during the pilot trials (especially with the regard to the shear stability), the polymer has been replaced by a liquid product Polysepar® K10-60C for further trials. The main properties of the polymers are given in Table 2-4.

Table 2-4: Properties of the polymers used during the pilot-scale trials

Parameter	PK35H	K10-60C
Active ingredients [%]	98	46-48
Cationic charge [%]	35	60
Type	granular, linear	cross-linked, liquid

2.4 Operating procedures during pilot-scale dewatering

In general, proper preparation of polymer was (and is) the basis for pilot-scale dewatering trials and full-scale dewatering. Setting up the pilot-scale decanter next to the full-scale dewatering unit on the WWTP ensured direct comparability of the results. Before starting the decanter, it was important to know the hydraulic and total solids limits.

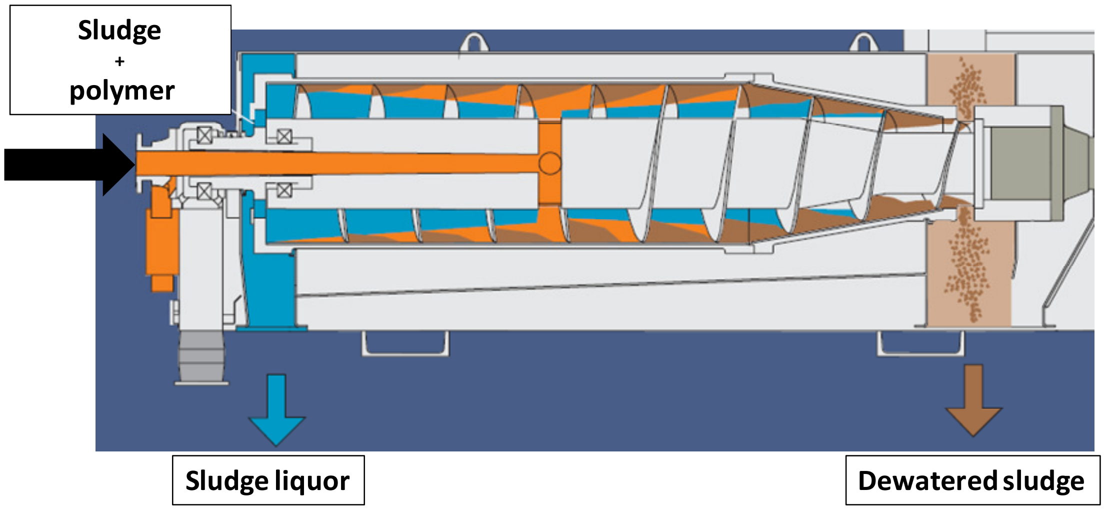
The general procedure to start the decanter in order to evaluate one specific setting has been as follows:

Dewatering trials started with a high speed difference until the centrate was clear without black flocs. Afterwards, it was possible to enhance the dewatering performance by reducing the speed difference in little steps. Once an adequate speed difference had been identified, it was absolutely necessary to run the pilot-scale system at a stabile dewatering performance for at least one hour. Sampling was possible when the torque of the screw remains constant. For representative sampling, it was important to collect sludge liquor and dewatered sludge for at least several minutes to set up mass balances in order to check the results.

3 Optimisation of dewatering performance by the variation of operational machine parameters

In the following chapter, the influences of single machine parameters on the dewatering results are summarised. Please note that the parameters might influence each other. General procedures to optimise the dewatering process, considering all machine parameters comprehensively, are given in chapter 3.5 and chapter 6.1.

3.1 Impact of feed rate



Feed rate	High	Low
Dryness of cake	increases	decreases
Separation ratio	decreases	increases

The feed rate (throughput) of the decanter has a significant impact on the dewatering performance when exceeding the limitation of hydraulic [m^3/h] and the total solids throughput [kg/h]. Both the sludge and the additional volume of the polymer dosage have to be taken into account for the calculation of the hydraulic throughput.

The results listed in Table 3-1 are related to the feed rate, expressed as hydraulic and total solids throughput of sludge *and* polymer. Comparing the results from line to line, the increase of TS_{cake} at higher throughputs is always combined with a reduction of the separation ratio.

Table 3-1: Influence of the parameter „throughput (feed rate)“ on the dewatering results

Varied parameters		Resulting parameters	
Hydraul. throughput [L/h]	**Solids throughput [kg/h]**	**TS sludge cake [%]**	**Separation ratio [%]**
273	5.2	20.8	95
349	6.7	26.3	91
442	8.9	30.2	67

($TS_{(in)}$ ~2,3; LOI ~64.; Temp. n.m.; Polymer: K10-60C; hydraulic limit: 400 L/h)

In practice, it is necessary to keep the feed rate below the hydraulic limit in order to avoid unusual dark centrate. That color indicates the transport of black flocs from the sedimentation process with the overflow of the weirs. In the last line of Table 3-1, the hydraulic limit has been exceeded, leading to a significantly diminished separation ratio.

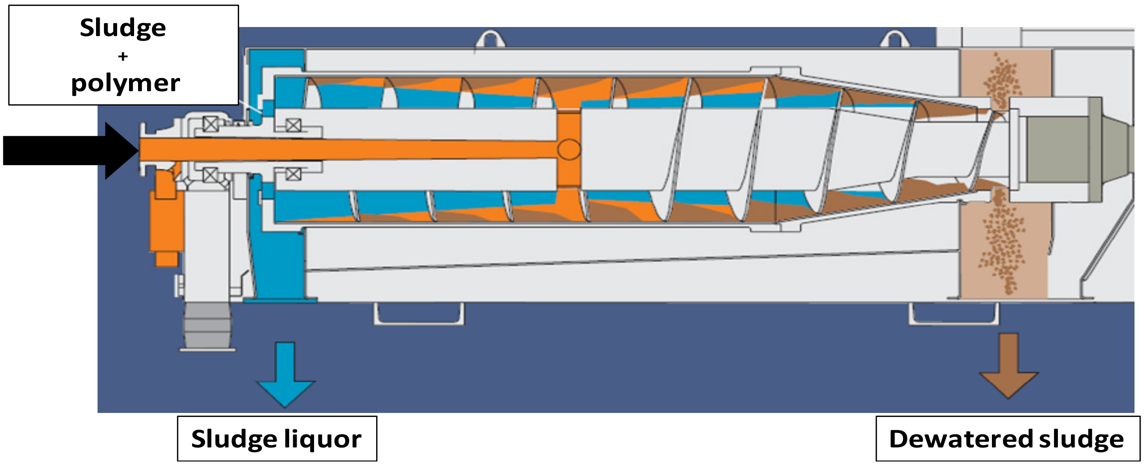
In addition, tests with varied feeding rates were also carried out in combination with different concentrations of the polymer solution from 0.1 to 0.4% active ingredients. The complete results are listed in Table 3-2.

Table 3-2: Complete results of trials with varied throughput ($TS_{(in)}$ 2,3-2,4; LOI ~64-67; Temp. n.m.; Polymer: K10-60C; hydraulic limit: 400 L/h)

varied parameters				resulting parameters		
polymer solution	**hydraulic throughput**	**solids throughput**	**dos-poly***	**TS sludge cake**	**seperation ratio**	**power load of the screw**
[%]	**[L/h]**	**[kg/h]**	**[kg ai/t TS]**	**[%]**	**[%]**	**[%]**
0.1	320	5.2	19.5	24.3	98.9	39
0.1	306	5.2	16.8	22.3	96.6	36
0.1	414	6.7	20.5	26.2	88.8	56
0.2	273	5.2	19.0	20.8	95.2	32
0.2	274	5.1	23.3	25.2	80.0	39
0.2	348	6.6	19.3	25.8	71.5	45
0.2	349	6.7	21.3	26.3	91.1	55
0.2	442	8.9	21.3	30.2	67.4	49
0.4	320	6.6	21.4	26.5	81.7	39
0.4	385	8.2	21.9	27.6	70.3	53
0.4	384	7.8	25 **	26.3	86.5	58
0.4	372	7.7	20 **	27.4	86.0	63

* standard point of dosage ** polymer dosage at the pump rotational speed difference: 0.7 rpm

3.2 Influence of the speed difference of the screw



Speed difference	Low	High
Dryness of cake	+	-
Separation ratio	-	+

The speed difference of the screw and the bowl has a direct influence on the retention time of the solids in the drying zone of the decanter and their compaction. As a consequence, it is one of the key parameters with regard to the dewatering results.

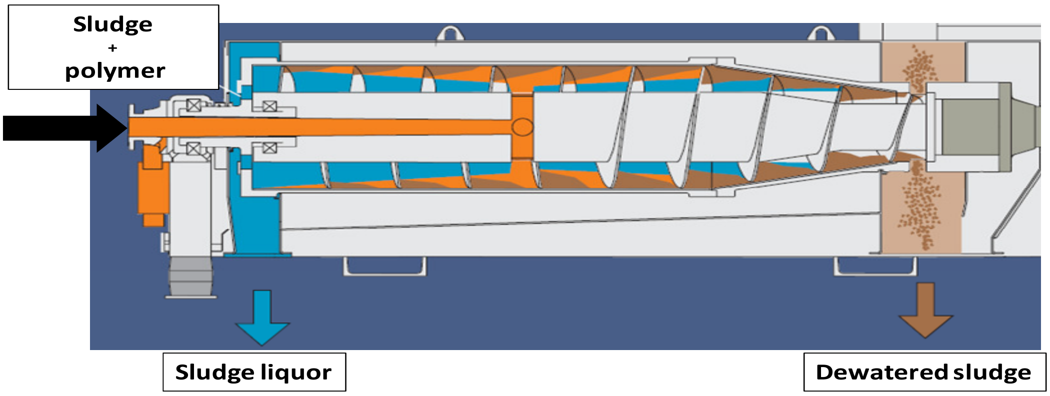
Generally, a small speed difference leads to an increase of the dry solids content of the sludge cake, but also a reduction of the separation ratio. Especially when the speed difference is reduced in *full steps*, the influence on the dewatering is obvious (Table 3-3; series 1).

Table 3-3: Influence of the parameter „speed difference“ on the dewatering results

Varied parameter	Resulting parameters	
Speed difference [rpm]	**TS sludge cake [%]**	**Separation ratio [%]**
2.0	18.4	99.7
1.0	21.2	87.4
machine parameters: throughput: 90% (sludge), inner diameter of weirs: 88 mm ($TS_{(in)}$ ~2,5; LOI n.m.; Temp. 41-42°C; Polymer: PK35H)		
1.6	18.2	97.9
1.5	18.9	99.7
1.4	19.9	93.2
1.2	19.9	83.7
machine parameters: throughput: 90% (sludge), inner diameter of weirs: 82 mm ($TS_{(in)}$ ~2,5; LOI n.m.; Temp. 40°C; Polymer: PK35H)		

If the speed difference is reduced below a critical level (even in small steps), a significant and sudden breakdown of solid/liquid separation could be observed (Table 3-3; series 2). See also chapters 0 and 3.5.

3.3 Impact of drum speed and relative centrifugal force



Relative centrifugal force	High	Low
Dryness of cake (TS)	increases	decreases
Separation ratio	decreases	no effect

The mechanically induced centrifugal field which leads to the solid/liquid separation depends on the inner drum diameter and the speed of the revolving drum. The drum speed can be varied easily during operation in order to find the optimum relative centrifugal force for the given system of decanter geometry, sludge properties and polymer features.

Dewatering tests were carried out with various centrifugal forces, ranging from 3,080 xg (maximum speed possible) down to 2,400 xg. In terms of dryness of the cake, an optimum was observed at 2,800 xg, corresponding with a slight decrease of the separation ratio (Table 3-4).

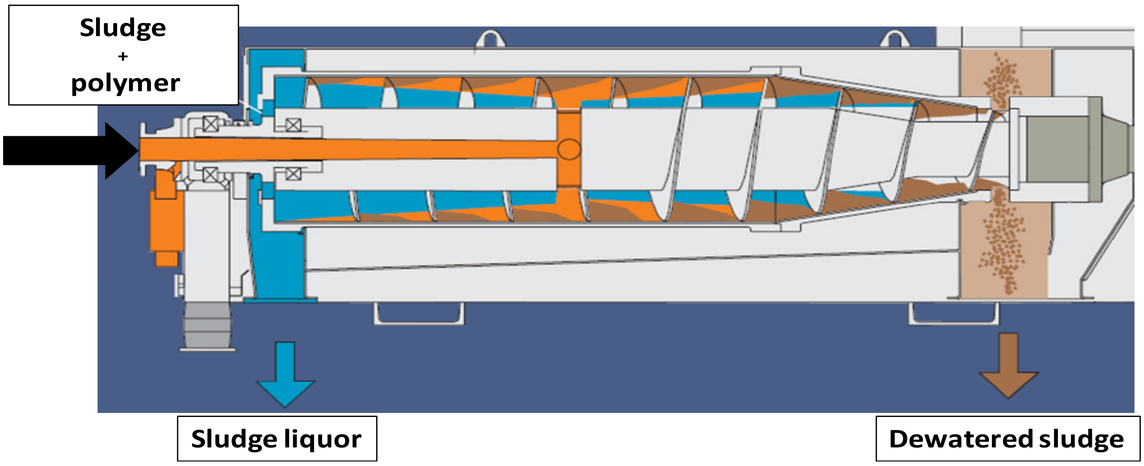
Table 3-4: Influence of the parameter „centrifugal force“ on the dewatering results

Varied parameter	Resulting parameters	
Centrifugal force [x g]	**TS sludge cake [%]**	**Separation ratio [%]**
3,080	22.9	99.2
2,800	23.9	98.1
2,600	22.9	99.3
2,400	21.3	99.2

($TS_{(in)}$ ~2,9; LOI n.m.; Temp. ~38°C; Polymer: PK35H)

Thus, the maximum operating speed is not always the optimum. During the trials, 2,600 xg has been set as standard. Usually, the geometry of the decanter limits the operable centrifugal force, because the solids sediment has to be transported in the dry zone against the angle of the cone.

3.4 Influence of the inner diameter of the weirs



Inner diameter of weirs	Minimum (82 mm)	Maximum (88 mm)
Dryness of cake	-	+
Separation ratio	+	-

The centrifugal forces lead to sedimentation of the solid flocs at the inner drum wall, while the centrate forms a ring above it. The thickness of the water ring in the drum is called *pool depth*. The centrate is removed by adjustable weirs which are usually installed below the cone. The cone is the tapered end of the drum. The dry zone is the area above the water ring in the cone. The length of this zone – mainly defined by the inner diameter of the weirs – can essentially influence the achievable dewatering result.

The variation of the weirs was evaluated at the beginning of the trials. Due to the generally poor dewatering results at this stage, the influence of the variation was low. Later on during the trials, the parameter "weirs" was only varied within the context of other parameters, because it interacts strongly with them (especially with the speed difference).

(Only) if the dewatering performance is optimised, a higher inner diameter of weirs might lead to increased dry solids content and a reduced separation ratio.

3.5 Optimised set of machine parameters

In the previous chapter, the influence of the machine parameters on the dewatering has been evaluated. The trials have shown that it is not useful to optimise one specific parameter without considering the others. When the dewatering performance is (below) average, the influence of single parameters (e.g. the weirs; see chapter 3.4) is low. Thus, a good operating point has firstly to be identified as a stable basis for further improvements. A helpful procedure might be:

1) Starting the decanter with 70% throughput with corresponding polymer dosage using a high speed difference until the centrate is clear.
2) Reduction of the speed difference (one of the key parameters with regard to the TS) in little steps just above the point of black flocs in the centrate.
3) Setting up a constant torque of the screw drive. Only a stable dewatering performance with a constant torque can be optimized systematically.

Then, the procedure to optimise the performance might be as follows:

4) Identification of an optimal rotational g-force should be carried out firstly after reaching a constant torque because it has little impact on other parameters.
5) Increasing the throughput with corresponding polymer dosage; re-adjusting the speed difference. It might be necessary to restart at this stage with a high speed difference because of enduring output of flocs in the centrate.
6) Finally, to adapt the separation ratio (e.g. reducing the SR deliberately to improve the dry solids content), the inner diameter of weirs might be changed. In this case, a complete new start of the procedure is compulsory.

General remarks:

7) At a high performance dewatering process, the system reacts more sensitive on variations, especially with regard to polymer dosage.
8) Improving the dewatering performance includes a suitable variation of parameters with skilled and motivated personnel.

Since most parameters influence each other, an optimized *set* of parameters is not the sum of optimised single parameters. Therefore, it might be necessary to change/optimise other parameters when focusing of *one* specific aspect, e.g. the influence of the inner diameter of the weirs.

Remark: Full-scale decanters have a continuous safety control system, depending on torque of the screw or the pressure. With a pilot-scale decanter, it is possible to investigate a wider range of operating machine parameters for optimisation because the operating personnel observes the dewatering performance at a high torque and the safety control is only used to avoid total clogging of the bowl.

4 Impact of sludge conditioning on the dewatering performance

4.1 Impact of polymer solution

4.1.1 Remark: Polymer screening and dosage

The physical/chemical properties of the polymer (solid/liquid; percentage of cationic loading; degree of cross linking; molecular weight...) have a high influence on the suitability for a specific purpose. If there are *any* changes in the whole sludge treatment system – e.g. changing sludge properties, but also different points of dosage or dewatering temperatures – it is recommended to verify the suitability of the "standard" polymer (see checklist in chapter 6.2). *Finding the "best" polymer has to be regarded as the first and essential optimisation step in sludge dewatering and as the basis of all further optimisation approaches*. See also DWA-M 350 (preparation and use of polymers).

The same applies for the optimum polymer dosage that should be checked regularly, especially when sludge properties change and/or operational parameters are modified (see also checklist).

During the pilot-scale trials (including the assessment of the machine parameters), two different polymers have been used:

- Granular polymer PK35H
- Liquid polymer K10-60C (see properties in chapter 2.3)

As already mentioned in chapter 2.3, the granular polymer turned out to be less suitable (especially with the regard to the shear stability of the flocs) and was therefore replaced by the cross-linked liquid polymer.

4.1.2 Concentration of polymer solution

The concentration has a significant influence on the viscosity of the polymer solution. If the viscosity is high, a higher mixing energy is needed for a proper contact of negatively charged particles (i.e., the sludge) and the cationic polymer. A proper contact is the basis for the creation of flocs that resist shear stress in a decanter. It has to be considered that a low concentration in combination with a high sludge throughput might leads to a hydraulic overload.

The influence of the concentration of the polymer solution has been assessed for different throughputs of 50% up to 90%, related to the sludge input (Table 4-1). Please note that the polymer solution has an *additional* influence on the throughput, especially when the concentration of the solution is low.

A higher concentration (see lines 1+2 and 3+4) leads to a reduction of the dry solids content in the sludge cake. Since the results might overlap with throughput-related effects, Table 4-1 also indicates that a higher throughput leads to an improved dewatering result, but a reduced separation ratio. It can be assumed that the remarkably low separation ratio at 0.2% solution and 90% sludge throughput is related to the possible overload of the system (see also chapter 3.1).

Table 4-1: Influence of the parameter „polymer solution“ on the dewatering results

Varied parameters			Resulting parameters	
Polymer solution [%]	**Hydraul. throughput [L/h]**	**Solids throughput [kg/h]**	**TS sludge cake [%]**	**Separation ratio [%]**
0.1	320 (50%)*	5.2	24.3	99
0.2	273 (50%)	5.2	20.8	95
0.2	442 (90%)	8.9	30.2	67
0.4	372 (90%)	7.7	27.4	86

$TS_{(in)}$ 2,3-2,4; LOI ~64-67; Temp. n.m.; Polymer: K10-60C; hydraulic limit: 400 L/h)
***in brackets: Throughput related to sludge only**

4.1.3 Contact time and mixing energy

The contact time polymer/sludge and the mixing energy are mainly defined by the point of dosage of the polymer solution and the geometry of the pipes and connections. The optimum dosage point depends on the properties of sludge and polymer; therefore, it is reasonable to provide different dosage points that can be varied easily during (full-scale) operation in order to adapt to changing properties (see also DWA-M 383). Different dosage points should already be considered during planning and construction of the dewatering system, because a refitting of new dosage points *after* construction is hardly possible.

In pilot-scale, the standard application of polymer solution is at the infeed tube of the decanter (see also Figure 2-1). The ***reduction*** of contact time was realized by the insertion of a feeding tube *in* the screw of the decanter. A positive side effect is the increased velocity of flow due to the reduction of the cross section. Using a perforated dead end tube, the polymer solution could be injected directly in the sludge, thus increasing the mixing energy.

Figure 4-1: Insertion of the polymer feeding tube in the screw (left) and close-up of polymer solution spraying out of the perforated tube (right)

An ***extension*** of contact time was realised by an upstream application of polymer solution ahead of the feeding pump. This also increases the mixing energy. Both the reduction and the extension have an impact on the shear stability of the flocs and the dewatering performance. The results are listed in Table 4-2. If needed, the parameter “polymer dosage” had also to be modified because of its strong interaction with the dosage point.

Table 4-2: Influence of the parameter „contact time/mixing energy“ on the dewatering results

Varied parameters		Resulting parameters	
Point of dosage	**Polymer dosage [kg ai/t TS]**	**TS sludge cake [%]**	**Separation ratio [%]**
3 m ahead of pump	20	23.6	88.0
At the pump	20	26.9	99.5
Standard	21	27.9	94.7
Applied in screw	21	26.9	94.0
Injected in screw	21	27.7	n.d.
3 m ahead of pump	18	23.9	77.3
At the pump	17	23.2	99.7
Standard	20	26.8	99.9
Applied in screw	18	26.4	89.4
Injected in screw	18	25.5	93.8

($TS_{(in)}$ 2,2-2,4; LOI ~65-66; Temp. 44°C.; Polymer: K10-60C)

Using a cross linked polymer (K10-60C) with an (optimal) dose of 20-21 kg ai/t TS, the contact time has had little impact on the TS of the sludge cake, but the separation ratio had an optimum at high mixing energies (=application at the pump). Only when applying the polymer ahead of the pump, both the TS and the separation ratio were remarkably lower.

With a reduced polymer dose of 17 to 18 kg ai/tTS, the influence of the point of dosage on the dewatering performance was more obvious. Then, the system reacts more sensitive on shear stress and consequently, it could be observed that an early application of the polymer leads to a reduction of the dry solids content due to the increasing instability of the flocs. An increased mixing energy at short contact times (application vs. injection in the screw) leads mainly to an improvement of the separation ratio.

Independently of the polymer dosage in case of the pilot trials, the standard application seems to be the best compromise between contact time and mixing energy, leading to the best dewatering performance and the best separation ratio. As for the identification of the “best” product, the point of dosage strongly depends on the properties of the sludge.

Further pilot trials therefore have been performed with the standard application.

4.2 Preheating of sludge

The preconditioning system for the preheating of sludge consisted of a 5 m^3 container and a spare heat exchanger with a volume of 3.8 m^3. The sludge has been circulated continuously through the system (Figure 4-2).

Figure 4-2: The sludge storage container (left) and the spare heat exchanger (right)

The assessment on the impact of the temperature on the dewatering process was carried out without preheating as the reference and preheated up to a maximum of 66°C before dewatering. A further part of the trials focused on the dewatering of sludge that was chilled after preheating for 1 h.

4.2.1 Digested sludge

The assessment of the thermal preconditioning of digested sludge has been carried out with thermophilic as well as mesophilic digested sludge.

The ***thermophilic*** sludge from WWTP KWS was digested with 55℃ and could be dewatered at 50℃ without further pre-heating (compared to 42℃ in full-scale) and 58℃ with additional pre-heating. The trials have been combined with variations of the polymer dosage. The results are given in Table 4-3.

The pre-heating of digested sludge had almost no influence on the $TS_{sludge\ cake}$ and the separation ratio, as well as the cooling of the sludge to 39℃. At high temperatures, the systems seems to react a little less sensitive on polymer underdosing (i.e., the polymer is more efficient at higher temperature due to reduced viscosity; see also 4.3), but there is no strong evidence of this assumption.

Table 4-3: Results of dewatering of thermophilic sludge

Varied parameters			Resulting parameters	
Trial	**Dewatering temp. [℃]**	**Polymer dosage* [kg ai/t TS]**	**TS sludge cake [%]**	**Separation ratio [%]**
No preheat.	50	22	28.1	99.3
No preheat	50	21	27.5	98.9
No preheat	50	18	26.0	97.7
No preheat	50	15	25.6	99.9
Preheat. 66℃	58	23	27.5	99.8
Preheat. 66℃	58	21	27.4	98.8
Preheat. 66℃	58	17	26.5	99.7
Preheat. 66℃	58	14	24.9	93.9
66℃ + cooled	39	20	26.6	97.8
66℃ + cooled	39	17	26.6	98.4

***concentration of polymer solution (cross linked K10-60C) : 0.2%; $TS_{(in)}$ 2,2-2,4; LOI ~66-67; machine parameters: throughput: 70% (sludge), weirs: 85 mm; speed difference: 0.7 rpm**

The ***mesophilic*** digested sludge taken from WWTP Salzgitter Nord has been dewatered at a temperature of 28℃ in pilot-scale (30℃ in full-scale at Salzgitter WWTP). After pre-heating, the sludge was dewatered at 56℃. The results of the trials are given in Table 4-4.

Table 4-4: Results of the dewatering of mesophilic sludge

Varied parameters			Resulting parameters	
Trial	**Dewatering temp. [°C]**	**Polymer dosage* [kg ai/t TS]**	**TS sludge cake [%]**	**Separation ratio [%]**
No preheat.	28	13.1	22.6	98.0
Preheat. 64°C	56	13.2	23.9	99.9
Preheat. 64°C	56	11.6	23.8	99.9
Preheat. 64°C	56	11.0	23.5	99.9
64°C + cooled	34	14.3	23.8	99.9
64°C + cooled	34	12.7	22.8	99.9
64°C + cooled	34	11.7	21.9	99.9

***concentration of polymer solution (cross linked K10-60C) : 0.2%; $TS_{(in)}$ 3,5-4,0; LOI n.m.; machine parameters: throughput (sludge): 70%, weirs: 88 mm; speed difference: 1.6 rpm**

Compared to themophilic digested sludge, the effect of pre-heating of mesophilic digested sludge was higher and led to an increase of $TS_{sludge\ cake}$ of max. 1.3% for +28°C dewatering temperature even when underdosing the polymer (11.6 kg ai/t TS, compared to 13.1 kg ai). Preheating might therefore be an option to save polymer and to (slightly) increase the dry solids content. In any case, the separation ratio was very good.

4.2.2 Primary sludge

Primary sludge of the WWTP of Braunschweig (TS = 4% and VS = 80%) has been dewatered at different temperatures up to 59°C and after being cooled. The results are given in Table 4-5.

Table 4-5: Results of the dewatering of primary sludge

Varied parameters			Resulting parameters	
Trial	**Dewatering temp. [°C]**	**Polymer dosage* [kg ai/t TS]**	**TS sludge cake [%]**	**Separation ratio [%]**
No preheat.	23	7	38.0	99.9
Preheat.	44	7	38.0	99.8
Preheat.	54	5	38.1	99.9
Preheat.	59	5	43.2	99.9
Preheat + cooled	42	4	35.7	99.9
Preheat + cooled	41	7	39.4	99.9

***concentration of polymer solution (K10-60C): 0.2%; $TS_{(in)}$ ~4.0; LOI ~76-80; machine parameters: throughput: 90% (sludge), weirs: 85 mm; speed difference: 2.0 rpm**

As usual for primary sludges, the TS after dewatering is generally much higher and the polymer demand lower, compared to digested sludges. Pre-heating up to 54℃ has no effect at all on the dry solids content; but at 59℃, a rapid increase was observed. It has to be questioned that an increase of only 5℃ could lead to +5% TS_{cake}; probably, the result is a non-repeatable outlier. Within this context, it has also to be considered that primary sludges are generally more inhomogeneous than excess- or digested sludges. As observed for the digested sludges, less polymer is needed at higher temperatures to achieve the same dewatering results.

4.2.3 Excess sludge

The dewatering trials were carried out with excess sludge of the Braunschweig WWTP that had been thickened to TS = 4.4% without any polymer dosage. VS was 78%. The sludge was pre-heated to 66℃ and was dewatered directly after pre-heating (~55℃) and after being cooled down to ~35℃. The results are given in Table 4-6.

Table 4-6: Results of the dewatering of excess sludge

Varied parameters			Resulting parameters	
Trial	**Dewatering temp. [℃]**	**Polymer dosage* [kg ai/t TS]**	**TS sludge cake [%]**	**Separation ratio [%]**
No preheat.	18	7	12.8	99.7
Preheat. 66℃	54	6	16.2	92.8
Preheat. 66℃	56	7	16.0	99.0
Preheat + cooled	35	8	15.7	99.7
Preheat + cooled	36	6	14.6	91.1

***concentration of polymer solution (K10-60C): 0.2%; $TS_{(in)}$ ~4.4; LOI ~76-78;**
machine parameters: throughput: 70% (sludge), weirs: 85 mm; speed difference: 4.0 rpm

As usual for excess sludges, the achievable TS after dewatering is generally much lower compared to digested sludges. In this case, pre-heating led to a notable increase of the dry solids content in the cake of >3%, corresponding to approx. +1% TS / 10℃. The positive effect was still observable after cooling to 35℃. In any case, underdosing the polymer had a notable effect on the separation ratio.

4.3 EPS and viscosity

The dewatering performance is generally depending on the rheological behaviour of sludge. The content of extra cellular polymeric substances (EPS) in a sludge matrix corresponds with the viscosity of sludge. In order to characterize the content of EPS, physical as well as chemical extraction methods were performed by the laboratory of ISWW.

- Extraction methods (d'Abzac et al 2010)
  Physical: Modified cationic exchange resin method (CER: DOWEX Marathon C)
  Chemical: Formaldehyde (FA) + NaOH
- Quantification:
  Polysaccharides: Phenol-sulphuric acid method (Frolund et al 1996) using Glucose as standard
  Protein: Lowry method (Frolund et al 1996) with Bovine serum albumin as standard

According to literature, different extraction methods usually lead to considerably different results of the EPS content and are therefore not comparable. Results achieved with the *same* extraction method are comparable, if the analyses are performed by the same person/laboratory.

In the context of pilot trials, rheological analyses were mainly performed during the pre-heating trials in order to correlate EPS and viscosity with (possible) changes of the dewatering performance. The results of the EPS analyses of different digested sludges are given in Figure 4-3 and Figure 4-4.

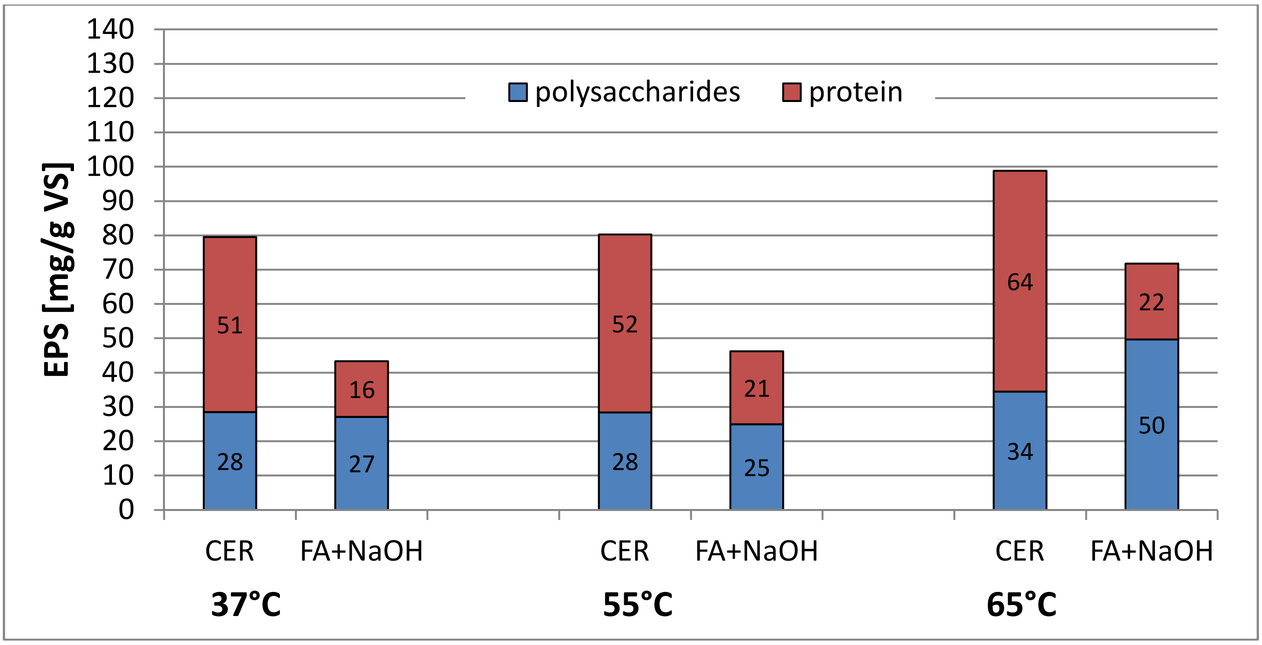


Figure 4-3: Results of the extraction of EPS from mesophilic digested sludge of WWTP Salzgitter (TS= 4.4%; VS= 52 %)

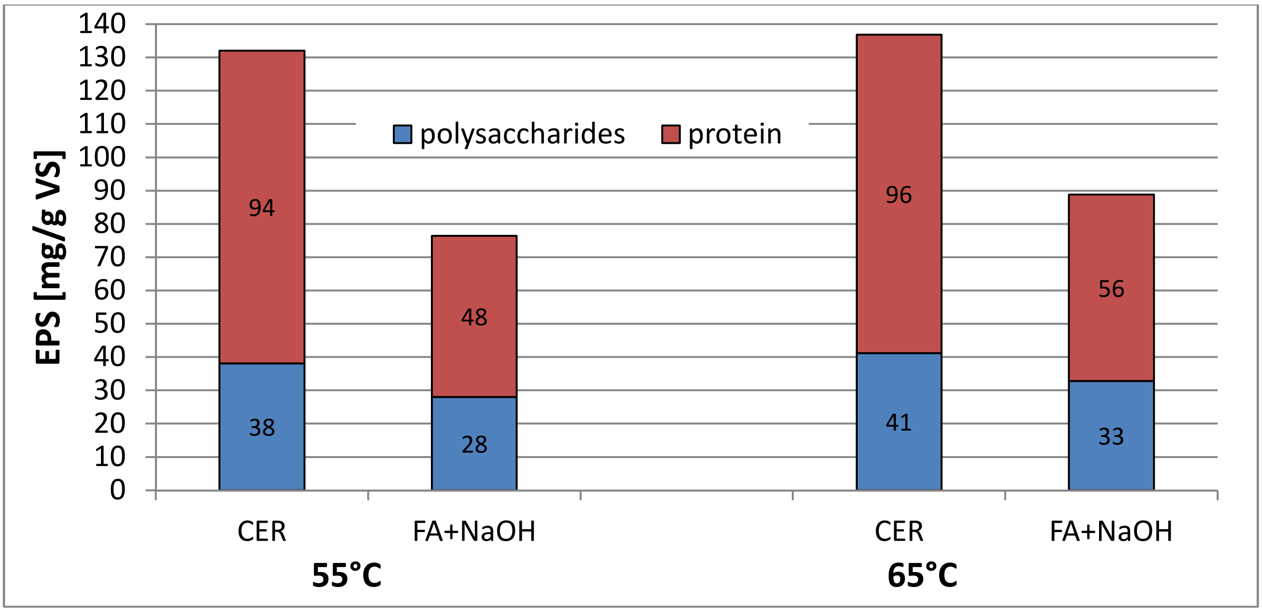


Figure 4-4: Results of the extraction of EPS from thermophilic digested sludge of WWTP Braunschweig (TS= 2.2%; VS= 67%)

The results prove that different methods are not comparable to each other. With regard to the protein content, the FA-NaOH-method yields only 1/3 to 1/2 of the CER-method. In contrast, the polysaccharide content is more or less in the same range.

In case of the ***mesophilic*** sludge, pre-heating up to 55℃ has no effect on the EPS. At 65℃; total EPS increases from 80 mg/g to 100 mg/g (CER-method), respectively from ~45 mg/g to 70 mg/g. For ***thermophilic*** sludge, there is only a slight increase of the EPS at higher temperatures.

The EPS-content of ***excess sludge*** with/without pre-heating has also been measured, with comparable results (Table 4-6).

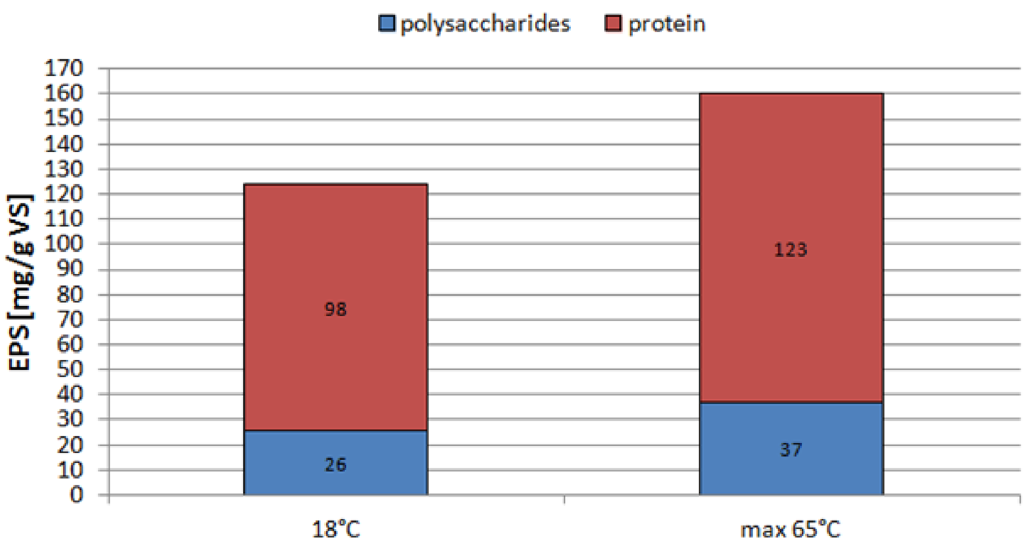


Figure 4-5: Results of the extraction of EPS from excess sludge

To conclude, pre-heating leads to a slight increase of the EPS, most obviously for excess sludges. Since the extraction method aims to measure the *total* EPS-content, these results are only comprehensible if there would be an additional production of EPS when bacteria suffer “heat stress”. Since the EPS analysis of this study was not designed to assess EPS and its fractions in detail, further research and an intensified analytical program is needed to clarify the influence of heat in the EPS-fractions.

Besides the EPS, the viscosity of excess sludge at different temperatures (kept constant for 1 h) has been measured with a rheometer (see details Figure 4-6). The results are given in Figure 4-7.

Standard preparation of sample:

- Screening 1 mm sieve
- Total solids = 5 %
- Temperature = 25 ℃

Determination of viscosity:

- Coaxial cylinder (clearance 1.44 mm)
- Temperature control system
- Shear stress at 500 s^{-1}
- Dynamic viscosity [Pa*s] = Shear stress/ velocity gradient

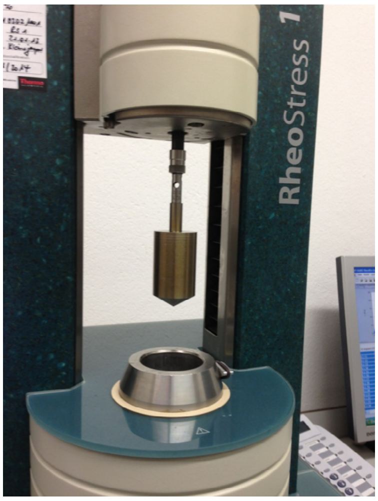


Figure 4-6: Main parameters of viscosity analysis at the laboratory of the ISWW

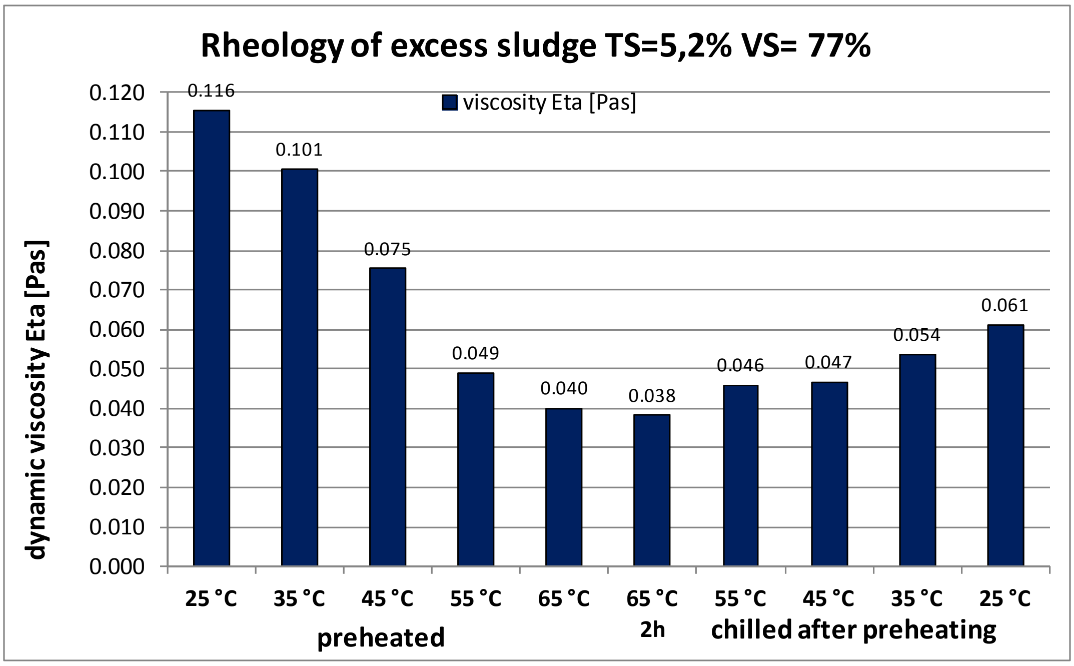


Figure 4-7: Dynamic viscosity of excess sludge at different temperatures

As shown in Figure 4-7, there is a reduction of viscosity when preheating up to 65°C, likely related to the common reduction of the viscosity of a liquid at higher temperatures. This result also corresponds to the reduced polymer demand described in chapter 4.2. Obviously, the reduction is non-reversible.

Since the non-reversibility cannot be explained by "liquid-related" effects only, it has to be concluded that heat also affects sludge bacteria in a non-reversible way, e.g. with regard to EPS and its different fractions. As already mentioned, the complex interactions of EPS (-fractions) and temperature needs to be assessed in a separate study.

5 Summary and outlook of trials

5.1 Summary of results

Machine parameters

The operational machine parameters have a significant influence on the dewatering performance, but cannot be regarded separately. Before optimising the machine parameters (and also before focusing on other aspects such as "polymer"), the performance of the system has to be good and stable (see procedure described in 3.5). After having reached the point of high performance, the variation of machine parameters might still increase TS_{cake} and/or improve the quality of the centrate. The interactions between the different parameters and also the influence of the polymer have to be considered, e.g. with regard to the return loads.

Polymer application

Depending on the properties of a polymer, the different *points of dosage* are more (or less) suitable for application. As a consequence, the dewatering performance and the separation ratio could be optimised by varying the point of dosage. In full-scale, it is recommended to provide different points of dosage *before* constructing the dewatering unit to be able to identify the "best" suitable polymer in terms of dewatering performance and dosage.

Over- and underdosing of polymer

Within the context of the pre-heating trials (see below), it could be observed that – due to reduced viscosity – the polymer dosage could be reduced when pre-heating the sludge.

Moreover, the polymer dosage has been varied regularly during the project. It can be concluded that polymer underdosing (overdosing is usually not of interest) has almost no effect if the dewatering performance is low. Thus, the general performance of the decanter should be optimised *before* reducing the polymer application; see procedure described chapter 3.5.

At this point, an (slight) underdosing usually leads to a reduction of the separation ratio. With regard to the economy of the whole dewatering process, long-term effects of increased return loads (that might counteract polymer savings) have to be considered. If the polymer dosage is further reduced, it can be expected that the TS_{cake} is reduced as well.

Due to the strong interactions/interdependencies with other (machine) parameters and the sludge properties, a precise procedure to save a specific amount of polymer *without* influencing the TS_{cake} cannot be recommended. Instead of reducing the polymer application, risking a reduction of the TS_{cake} in full-scale, it is certainly more important to check polymer preparation and optimal dosage regularly as described in chapter 4.1.1

Effects of pre-heating and cooling

Depending on the type of sludge, pre-heating leads to an increase of the TS_{cake} and/or to a reduced polymer demand (see above). The increase of TS_{cake} was most obvious for excess sludge, where a value of +1% TS_{cake} for each 10℃ could approximately be reached. For mesophilic digested sludges, pre-heating had only a small effect on the TS_{cake}; for thermophilic digested sludges, “no” effect could be observed.

If any, cooling down has rather reverse effects and is therefore not reasonable.

5.2 Comparison of pilot- and full-scale dewatering

General transferability

As shown in the previous chapters, the influence and the potential of a specific procedure/approach cannot be defined by exact figures due to the strong interdependencies with other parameters. Moreover, every sludge “reacts” different on a specific approach, depending on its properties. As a consequence, a *quantitative* prediction of full-scale optimisation potentials is connected with high uncertainties and therefore not reasonable.

Apart from this restriction, the results of the pilot-scale trials are *qualitatively* transferable to full-scale, as well as the general procedures to indentify a good operating point – the basis of all optimisation steps – and the procedures to identify a suitable polymer.

Application area and advantages of a pilot-scale decanter

Even if a full-scale unit is more stable and responds less sensitive on changes, a systematic evaluation of different parameters in full-scale is not feasible, neither with regard to the general effort, nor with regard to the safe operation of the whole system. Moreover, the variation of the parameters is usually limited by a safety control system, depending on torque of the screw or the pressure.

In contrast, compared to full-scale dewatering, a pilot-scale unit can be operated close to the operational limits or even beyond, because the quantity of sludge treated with a pilot-scale unit is negligible (approx. 2% of total volume in case of Braunschweig). Thus, there are scarcely any risks of disturbing the full-scale plant operation even in case of a complete breakdown of pilot-scale dewatering. As for a full-scale decanter, a pilot-scale unit might also be equipped with a safety control system; but limits set by the system might be exceeded more easily.

With regard to the *machine parameters*, it is possible to investigate a wide range of parameters for optimisation within a short period of time. Depending on the type of sludge and it properties, *general* optimisation potentials can be revealed that could then be transferred and verified in full-scale.

The same applies for the assessment of *polymer-related* questions. With a pilot-scale decanter, it is easily possible to check the type of polymer, the dosage and the dosage point. If an approach to optimise the dewatering performance and/or reduce the polymer dosage is identified, the results can then be transferred to full-scale, e.g. by using the same polymer with the same mixing energies as identified in pilot-scale.

Furthermore, a pilot-scale unit can be used to produce a major amount of *sample material* (e.g. some m^3 of sludge liquor or some kg of dewatered sludge with specific properties) for further lab- and pilot-scale trials, independently from the full-scale operation.

If transferring the results of a pilot-scale decanter to full-scale – especially when changing operational- and machine parameters – the limits provided by the manufactures of the decanters with regard to the expiration of guarantees (...) have to be considered.

5.3 Outlook

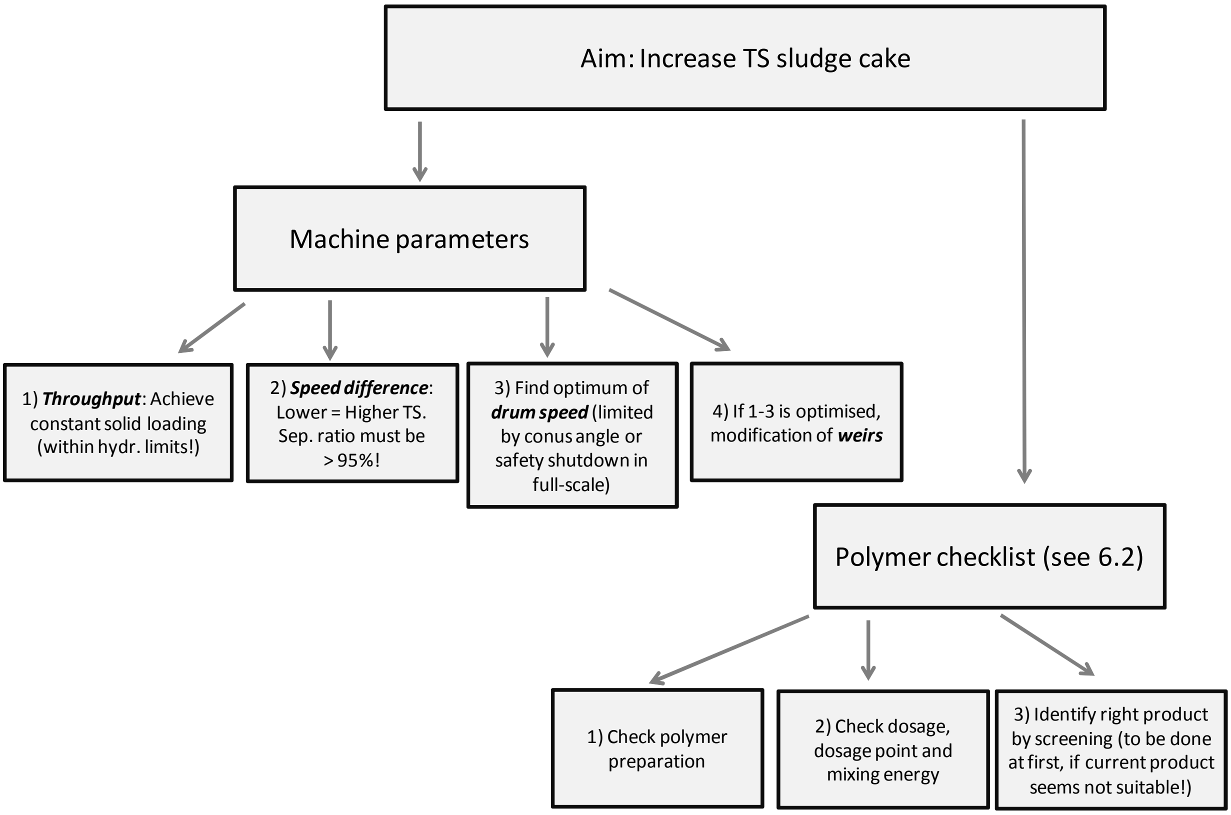
Within this project, the influence of various aspects (machine parameters, polymer...) on the dewatering result was evaluated. Procedures to indentify a good operating point could be derived, as well as recommendations to optimise polymer dosage and use. Since the project was focused on a general “screening”, further projects should rather focus on single aspects, but with a more detailed approach. The complex interactions of viscosity, EPS and dewatering are still widely unknown and require fundamental research with high analytical effort.

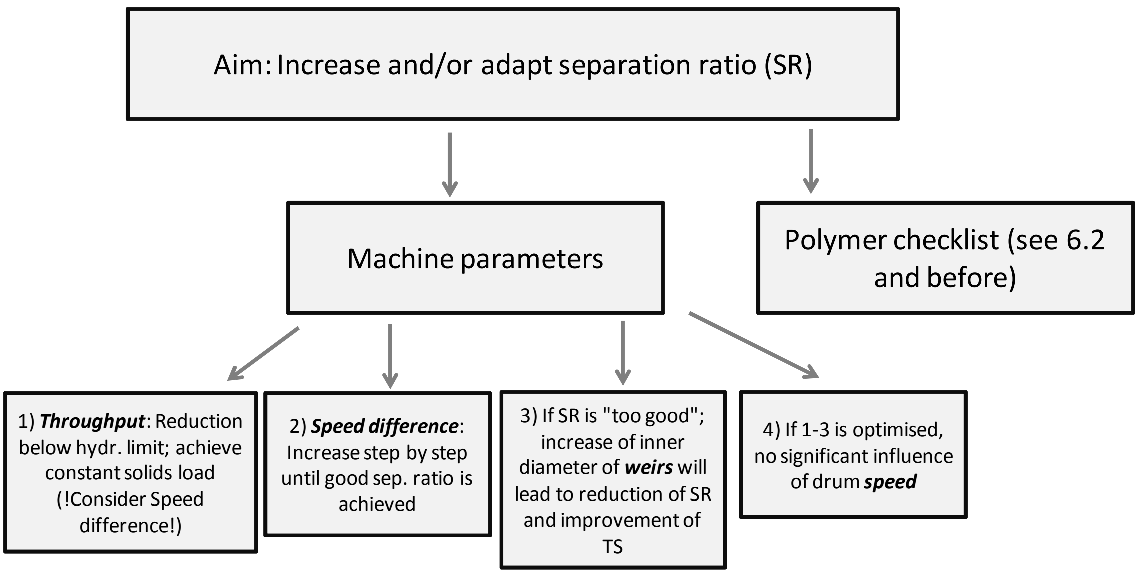
6 Annex

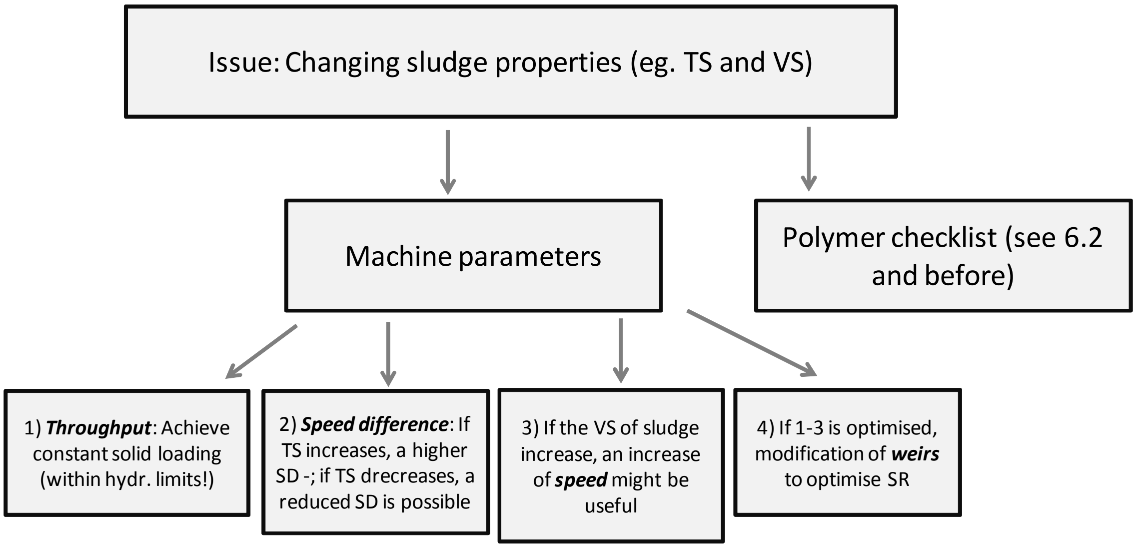
6.1 Decision trees for optimisation / Operational procedures

The following “decision trees” summarise the procedures to optimise sludge dewatering, focusing on different aims and issues. Most commonly, the TS of the sludge cake is the major intention, as well as the optimisation of the separation ratio (in this context, the term “optimisation” also refers to the reduction of a SR that is “too good”). Besides, seasonally changing sludge properties also give reason to optimise and adapt sludge dewatering.

The decision trees refer to the procedures described in chapters 3.5 and 6.2 and should be considered as a recommendation. Numbers describe a hierarchy; i.e. optimisation step 1) should be done first and the modification of weirs usually at the end (see chapter 3.4 for explanations). Please note that the steps might interact with each other.







6.2 Polymer checklist

As already mentioned in chapter 4.1.1, the proper preparation of polymer is the basis of a good dewatering performance and pre-requisite of further optimisations (e.g. of the machine parameters according to the aims and procedures described above). Polymer preparation and performance might be assessed by the following protocol:

- **Polymer screening (e.g. 2 to 4 times a year)**
    - Changing sludge properties (summer/winter) may require different polymers
    - Linear or cross-linked polymer
    - Percentage of cationic charge and degree of cross-linking
    - Assessment of polymer dosage (also to be verified monthly with “easier” methods, see below)
- **Dosage, contact time and mixing energy (e.g. monthly)**
    - Dripping test to verify polymer dose and shear stability
    - Check polymer application (different points of dosage, mixing energy…)
- **Preparation of polymer solution (could be checked daily)**
    - Comparison of consumption and dosage
    - Total solids of polymer solution
    - Visual check of polymer (clusters)

7 References

Frolund, B., Palmgren, R., Keiding, K., Halkjaer-Nielsen, P. (1996): Extraction of polymers from activated sludge using a cationic exchange resin. Wat. Res. 30 (8), 1749-1758

Paul D'Abzac, François Bordas, Eric Van Hullebusch, Piet N. L. Lens, Gilles Guibaud (2010): Extraction of extracellular polymeric substances (EPS) from anaerobic granular sludges: comparison of chemical and physical extraction protocols. Appl. Microbio. Biotechnol. 2010 85: 1589-1599

Stahl, W.H. (2004): Industrie-Zentrifugen. Bd. I + II; DrM Press, Männedorf

DWA (2008): Merkblatt M-383 "Kennwerte der Klärschlammentwässerung"

Kopp, J. (2009): Theoretische Grundlagen zur Entwässerbarkeit von Schlämmen. Fachtagung der VSA-Kommission „ARA", 13. März 2009

DWA (2013): Merkblatt M-350 "Aufbereitung und Einsatz von polymeren Flockungsmitteln zur Klärschlammkonditionierung - Entwurf"