WP1 – Carbon extraction for energy recovery

D 1.2: Design and performance of advanced primary treatment with microscreen

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Deliverable 1.2	***Design and performance of advanced primary treatment with microscreen***
Related Work Package:	1
Deliverable lead:	Hydrotech
Author(s):	Petter Olsson & Carles Pellicer-Nàcher
Contact for queries	Petter Olsson (petter.olsson@hydrotech.se)
Grant Agreement Number:	n° 641661
Instrument:	Horizon 2020 Framework Programme
Start date of the project:	01.07.2015
Duration of the project:	36 months
Website:	www.powerstep.eu
Abstract	This deliverable describes Guidelines for design and operation of advanced primary treatment with microscreen. Technical specifications including pre-treatment, mesh size, hydraulic velocity, chemicals (substances, doses, contact times), operational requirements (backwash, cleaning) and operational performances (removal rates, backwash sludge quantity and quality) are presented with data gained from the two Case study site trials in Westewitz (Germany) and Sjölunda (Sweden)..

Dissemination level of this document

X	PU	Public
	PP	Restricted to other programme participants (including the Commission Services)
	RE	Restricted to a group specified by the consortium (including the European Commission Services)
	CO	Confidential, only for members of the consortium (including the European Commission Services)

Versioning and Contribution History

Version	Date	Modified by	Modification reasons
v.01	2018-02-25	Petter Olsen	1st Draft
	2018-03-10	Rabea-Luisa Schubert	1st review
v.02	2018-03-27	Petter Olsen	2nd Draft
	2018-04-20	Boris Lesjean	2nd review
v.03	2018-05-13	Petter Olsen	Final version reviewed Christian Loderer
Final	2018-05-25	Petter Olsen	Based on the Feedback from Christian Loderer

Table of Content

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

List of figures

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

List of tables

Glossary

BOD: Biological Oxygen Demand

BW%: Backwash Frequency

COD: Chemical Oxygen Demand

CS1: Case study 1

HCT: Hydrotech Chemical Trolley-Chemical cleaning

HDF: Hydrotech Drumfilter

HPC: High pressure cleaning

HRAS: High Rate Activated Sludge

HSF: Hydrotech Disc Filter

P: Phosphorus

SBR: Sequencing Batch Reactor

TSS: Total Suspended Solids

TS: Total Solids

TST: Thickening and Storage Tank

VWT: Veolia Water Technologies AB

WP: Work Package

WWTP: Wastewater Treatment Plant

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Executive summary

Within the POWERSTEP project, Work Package 1 addresses the enhanced extraction of organic matter from municipal wastewater in order to increase energy recovery through digestion. Two large-scale demonstration plants using the microscreen technology from Hydrotech (Veolia Water Technologies AB, Sweden) were built and then operated as primary treatment after screening and grit removal in the wastewater treatment plants (WWTPs) of Westewitz (2000PE, Germany) and Sjölunda (300000 PE, Sweden). Both plants also included coagulation and flocculation tanks as well as dosing systems to increase and control of the carbon extraction.

This report presents a brief description of the WWTPs where the two case studies took place and also details the equipment used on both sites. It also includes the results obtained during the study with different operating strategies including e.g. turbidity- and flow-proportional dosing. Another dosing strategy described in this report was developed and evaluated within the Powerstep project, and is based on a feedback control loop where the chemical doses is optimized in order to achieve a targeted effluent turbidity.

The results from both sites show that TSS and total COD correlates well with turbidity and thus the feedback control loop can be used to target a specific effluent concentration of both these fractions. Turbidity-, TSS- and total Phosphorus-reductions above 90-95% could be obtained with chemically enhanced microscreening when dosing coagulant and polymer. Total COD-reduction of up to 80% could also be obtained during periods with high influent concentrations. At average conditions it was possible to reach approximately 65% COD-reduction as the soluble fraction was too high to allow for higher extraction rates. Without chemical addition the TSS-reduction was in the range of 30-60% and total COD-reduction 10-60% depending on the influent concentration.

No major differences in reduction rates were seen between 40 vs. 100µm filter media suggesting that the latter is more suitable for the application as the hydraulic capacity will be higher and the need for maintenance due to media fouling will be lower. Discfilter can be used in primary applications with fine pre-screening (1-2 mm) and grit removal upstream when no chemicals are dosed upstream. However, the drumfilter is a more robust and flexible microscreen for primary treatment as it can be used with pre-screening up to 5-6 mm and both with and without chemical enhancement. In both cases it was possible to use the filtrate for the backwash either by installing a self-cleaning strainer or using self-cleaning nozzles.

Typical sludge production for the filters after chemical cleaning during the tests was 1-3 % of the total influent flow and with dry solids content typically in the range 1-2% depending on operation settings. Optimization campaigns to increase the dry solids content could not be undertaken, as the plants did not allow easy evacuation of thicker sludge. The sludge from the filters could easily be dewatered with a screwpress to reach 25-45% dry solids content depending on operation settings and sludge quality.

1. Introduction

TSS in wastewater can be the source of many environmental and health-related problems in the receiving water bodies. Early TSS removal in primary treatment can decrease the load of certain pollutants such as Chemical Oxygen Demand (COD) on subsequent treatment stages and hence contribute to the minimization of the footprint and resource use (e.g. oxygen or energy) in downstream treatment steps (Siegrist, 2008).

Producing more biogas via sludge digestion is the key to achieve energy-neutral or even energy-producing WWTP, and it goes hand in hand with an efficient primary treatment to remove as much primary sludge as possible from the system (30-80% of total COD) prior to biological treatment. Many technologies, including conventional primary clarifiers, can ensure an efficient withdrawal of the primary sludge, and reduce the needs for aeration in the biological treatment downstream.

Primary settlers based on gravity settling are the most common type of primary treatment, either as standard clarifier or as lamellar settler (e.g. Marquette-Lez-Lille WWTP/FR, 625,000 PE). Typical performances are in the range of 50% suspended solids reduction, corresponding to around 30% of total COD reduction. The same performances can be achieved with microscreens (discfilters and drumfilters) on a much more reduced footprint (only 20% of the footprint of conventional settlers), as seen in Agnières-en-Devoluy WWTP/FR (7,000 PE, started up in 2010). Associated to coagulation and flocculation, it has been proved in pilot trials that up to 70-80% COD removal can be achieved, i.e. even higher performance than other CEPT (chemically-enhanced primary treatment) or high-load biological stage in a two-stage process (Kirchbichl WWTP/AT, 100,000 PE), that achieve max 50% COD extraction.

1.1. Microscreens

Microscreens are gravity-driven and self-cleaning units designed to achieve high performance solid separation with minimal footprint and low energy consumption. In microscreens water flows into a central drum, which supports weaved media mounted in discs (Discfilters, Figure 1) or on custom-made panels mounted directly on the drum (Drumfilters, Figure 2). The treated water, which is filtered by gravity, accumulates in the tank or channel that contains the mentioned drum and leaves the ensemble also by gravity. During filtration, solids are caught on the filter panels, leading to an increase of the filtration resistance and ultimately to an increase of the water level in the central drum. When the water level difference in the drum and outside the drum reaches a maximum value, the drum starts rotating and backwashing at 8 bar is initiated with a set of nozzles aligned outside the filtration elements. The backwash water permeating through the filter pores releases the solids retained on the inner side of the filter, which are collected in a tray mounted inside the drum. Filtration is not stopped during backwashing and filtrate can be used as rinsing media. In case of filter overloads, the water that cannot be processed can be by-passed via a set of weirs installed at the filter inlet. These overflows can be either mixed with filtrate or disposed separately.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

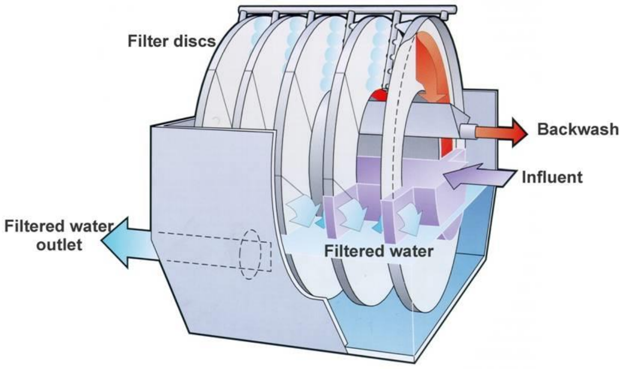

Figure 1: Discfilter working principle

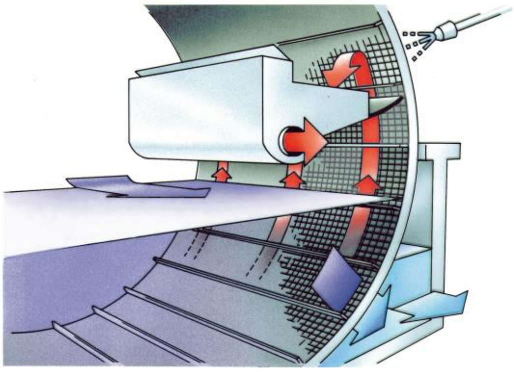

Figure 2: Drumfilter working principle

Microscreens can be delivered self-contained in steel or plastic tanks with an integrated control system and hardware to initiate, maintain and stop the self-cleaning mechanism. Furthermore, packing of filtration media is optimized in order to minimize footprint. These options make drum- and disc-filters turnkey options for water treatment with minimal construction and operation costs. Energy consumption can range from 5 to 30 Wh/m^3, depending on the type of filtration cloth used (10-1000 µm pores), the type of chemical pre-treatment applied, and the total suspended solids (TSS) loading pattern (Kängsepp et al., 2016; Remy et al., 2014).

1.1.1. Microscreens in primary treatment without chemical addition

Primary treatment is often performed in rectangular or circular sedimentation basins where the wastewater particles are allowed to settle at overflow rates of 1-2 m^3/m^2/h (Metcalf & Eddy Inc et al., 2002), taking the tank footprint area as reference. Microscreens (Drum or Discfilter) allow loading rates 10-20 times higher than in clarifiers and still achieve similar or even greater TSS removals. As the filter area in a microscreen is optimally packed within the footprint of the equipment, the space required for installation can be substantially reduced. It is recommended that the equipment is preceded by screening followed by grit and grease removal. Without chemical addition, removals of about 50% of the TSS (equivalent to the removal efficiency obtained in primary clarifiers) are attainable. This percentage typically corresponds to 20% in BOD-removal (Rusten and Odegaard, 2006).

1.1.2. Microscreens in primary treatment with polymer addition

TSS removals can be enhanced with respect to the above case by adding polymer in a flocculation stage upstream of the microscreen. With a correctly designed flocculation process, TSS removal in the order of 70-90% can be achieved without increasing considerably the sludge production (no chemical sludge is formed due to precipitation of dissolved components) and a polymer dose in the 2-4 mg/L range. The reduction of particulate organic pollutants will follow accordingly. Additionally, this configuration allows for dissolved fractions of phosphorus to remain in the water, which could be of interest in certain applications (Väänänen et al., 2016).

1.1.3. Microscreens in primary treatment with coagulation and flocculation

Coagulants and flocculants can be added upstream the microscreens in order to improve the filterability of the particles, precipitate dissolved Phosphorus (P), colloidal matter, and enhance the TSS and COD removal efficiencies up to 95%. Hydraulic retention times are minimized to a few minutes and wastewater flow is kept turbulent, allowing for real-time process control, lower greenhouse gas emissions, and maximization of the energy recovery from the organic carbon present in the wastewater, while minimizing the chemical dose required (Väänänen et al., 2016).

1.2. Objectives

In case studies 1 (Westewitz WWTP, Germany) and 2 (Sjölunda WWTP, Sweden), POWERSTEP will further explore and optimise the microscreen technology as advanced primary treatment for maximum carbon extraction with two design geometries (drum filters for smaller units and disc filters for larger units), targeting C-extraction rates beyond state-of-the-art processes such as primary clarifiers or lamella settlers and using a more compact design. More in detail, the following goals are defined:

- Optimise two microscreen design for primary treatment (drumfilter and discfilter)
- Reach up to 80% COD extraction from raw wastewater (today: max. 50%) in stable operation
- Verify the small footprint: < 20% of space required for conventional primary clarifier

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

2. Primary treatment with Hydrotech drumfilter at Westewitz WWTP

2.1. Site introduction Westewitz WWTP

Westewitz WWTP belongs to the Abwasserzweckverband Döblen-Jahnatal and is located in a rural area approx. 70 km SW of Leipzig, Germany. The plant was built and commissioned in 2009 and is operated by OEWA Wasser und Abwasser GmbH (OEWA Water and Wastewater Ltd.). The catchment area mainly consists of domestic wastewater and wastewater from a local hospital and it is connected to the WWTP via a separate sewer system (OEWA, 2012), which means that rainwater is separated from the municipal wastewater and therefore the influent is more concentrated than in combined sewer systems.

The plant is designed for 2000 PE (design loads in Table 1) and it is classified as a class 2 WWTP according to the German federal regulation. However, OEWA as an operator has applied stricter effluent requirements in order to lower the discharge fees (Table 2). The wastewater can be classified as medium-low strength (Henze et al., 2008).

Table 1: Design parameters WWTP Westewitz (OEWA, 2012)

Inflow volume	Peak inflow volume	Water quality parameter	Influent Concentrations	Influent Loads
[m³/d]	[m³/h]		[mg/L]	[kg/d]
390	38	BOD_5	308	120
		COD	615	240
		TSS	359	140
		TKN	56.4	22
		TP	9.23	3.6

Table 2: Effluent requirements at Westewitz WWTP (OEWA, 2012) for either qualified grab samples or two hour composite samples. 4 out of 5 consecutive samples must be below the limit value to fulfil the requirements.

Parameter	Threshold values for effluent quality for the OEWA	Threshold values for effluent quality according the law (AbwVO)
BOD5 [mg/l]	<40	<25
COD [mg/l]	<70	<110
TN [mg/l]	<18 (for T >= 12°C)	-
TP [mg/l]	<8	-

2.1.1. Treatment steps at the Westewitz WWTP

The WWTP in Westewitz prior to the changes made for the Powerstep-project consisted of mechanical and biological treatment as well as sludge thickening by gravity (Figure 3). The raw wastewater was pumped from the inlet pumping station via a compact mechanical pre-treatment system with 6mm drum screen (punched holes) and a hydrocyclone into another a pumping pit. The mechanically treated water was fed into the two SBRs on site. In the SBRs the wastewater was treated biologically, including biological phosphorous removal, intermittent nitrification, and denitrification. The processes were controlled by online measurement of dissolved oxygen and were followed by settling and decanting. Sludge escape of biomass was prevented by turbidity control of the discharged water.

The biologically treated and clarified wastewater from both reactors was discharged via a drainage well into a small stream. An adjustable amount of excess sludge was withdrawn from the SBRs during sedimentation to keep a constant sludge concentration in the reactors as well as a stable sludge age. The withdrawn excess sludge was pumped to a thickening and storage tank (TST), which dewatered the sludge as much as possible before transport and disposal. The larger particles settled to the bottom of the tank, leaving a supernatant at the top. The supernatant was then manually pumped back to the pumping pit again, acting as return load to the biological process. As the thickened sludge was transported to a larger routing WWTP for disposal, the solid content should be> 10 g/L for efficient transport of the sludge.

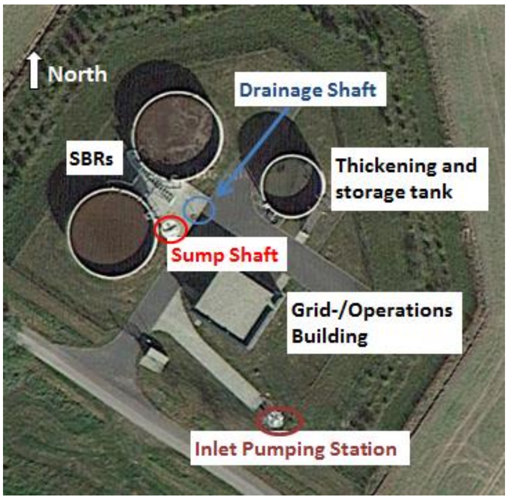

Figure 3: Aerial image of the original WWTP Westewitz with naming of the facilities

2.1.2. Upgrade with microscreen for enhanced carbon extraction

In the scope of WP1 the primary treatment process at Westewitz WWTP was expanded (Figure 4 and Figure 5).

Figure 4: Left: Aerial image of the WWTP Westewitz after installation of the filtration plant (encircled in red); right: Front view of the containers of the filtrations plant located between the SBRs.

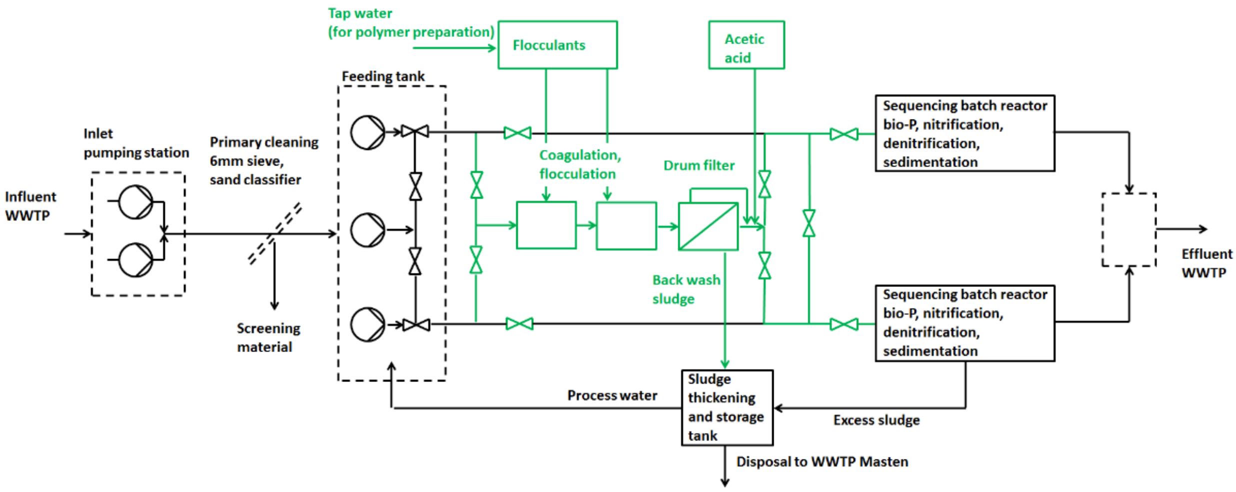

Figure 5: Process flow diagram of the WWTP Westewitz with advanced primary treatment

Frequency controlled pumps

For precise dosing of chemicals, the inflow to the drumfilter should also be as stable as possible. As the inflow of the WWTP varies considerably in the plant, flows to the drumfilter were buffered in the pumping pit by frequency controlled pumps. Further information on the microscreen technology and operation is given in Deliverable 1.1 ("Optimized design of microscreen and periphery for primary filtration").

Piping and flow meters

To allow the several operating modes in feeding the SBRs and the drumfilter, a change in the WWTP pipeline construction including the assembly of automatic flow distribution valves was necessary. The plant was also upgraded with flow meters (Proline Promag W 400, Endress and Hauser) to obtain the volumes of the SBR and drumfilter inflow.

Sensors

- **Nitrate sensors:** For online monitoring of the nitrate concentration Nitratax sensors from Hach were installed in both SBRs.
- **Turbidity sensors/transmitter:** Continuous measurement and logging of turbidity in the influent and the effluent of the microscreen plant were performed with Solitax SC sensors from Hach. The influent sensor was located in the pumping pit and was also used for control of the turbidity-proportional dosing of chemicals. The effluent sensor was mainly used for control of the filtration performance, but also for dosing control during tests performed to obtain a steady effluent quality. Both sensors were connected to a SC 1000 control unit from Hach for data interpretation and further transmission to a PLC. Turbidity data was used to estimate the TSS, COD and TP removal via correlation factors calculated by comparing online data to data obtained by analyzing TSS, COD, and TP in grab samples.

TSS-controlled process water pump

For optimized supernatant withdrawal from the TST, the manually operated process water pump was replaced by an automatic pump controlled by TSS level in the supernatant, which allows the supernatant to be pumped at given times or triggered by an external signal. The pump can be moved vertically through the TST and sensor detects the TSS concentration at the actual position. If the concentration is lower than a predefined value the pump starts and the found supernatant is pumped to the influent pumping pit.

Filter container

The filter container (the top container,

Figure 6), features coagulation- and flocculation-tanks upstream the microscreen. Both coagulant and polymer can be injected into the liquid stream in order to ensure full dispersion and highest efficiency. Top mounted mixers ensure effective particle contact during the wastewater residence time in both tanks. Coagulation and flocculation tanks are covered and the air phase can be continuously extracted by two fans.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Figure 6: The filter container at Westewitz WWTP, with coagulation tank, flocculation tank, drumfilter and control cabinets.

The drumfilter used ensures robust particle removal even with the existing 6 mm pre-treatment screen. The filter is automatically backwashed on demand by the installed BW-pump when a set differential pressure is reached, the backwash then continues until a preset lower differential pressure is. One redundant backwash pump was installed in order to ease maintenance and ensure continuous operation. Filtrate is used as backwashing media, and a self-cleaning strainer installed in the backwash line protects the backwash nozzles from being blocked by particles present in the filtrate. The backwash line is equipped with a flow meter and a pressure transducer to alert the operator of blockages and malfunctions in the filter cleaning system. A valve can be used to change the backwash operating pressure (Figure 7).

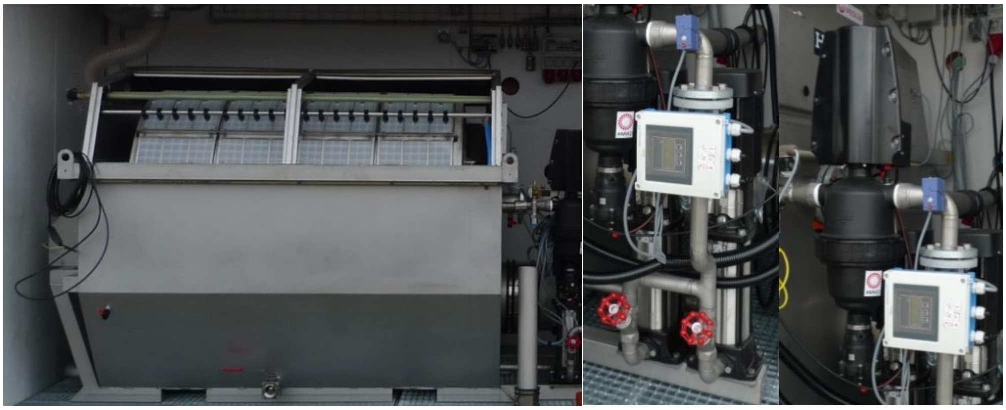

Figure 7: Filter unit and ancillary equipment in the backwash line

The filter features two additional cleaning modes designed to wash the filter in case of clogging. The high-pressure backwash would be used when clogging is first detected by the operator. A set of nozzles would then spray water at 80 bars in order to slough biofilm and other sticky fouling agents blocking the pores of the weave. Secondly, additional automatic chemical cleaning can be considered under acidic or basic conditions in order to ensure complete removal of mineral precipitates or biofoulants.

The filter unit is covered, and the air phase is connected to the ventilation system earlier mentioned, reducing the health risks for the operator.

Water flows by gravity through the whole treatment train. Effluent and sludge are led by pipes into the SBRs and the TST, respectively (Figure 8). Influent was sampled in the pump sump after sand and grit removal, effluent was sampled in a valve placed in the filtrate tank of the Drumfilter, and sludge out of the sludge effluent pipe, before the reject felt in the TST by gravity.

Figure 8: Sludge storage tank and piping connections at the Westewitz WWTP

Chemical container

In order to maximize the space in the filter container, chemicals, dosing equipment and cleaning-equipment are stored in the lower container of the assembly. Being at ground level also facilitates the loading and unloading of chemicals. Coagulant (dosed into the coagulation tank) was used at the plant for P removal and as flocculating agent for colloidal COD. Acetate (dosed in the filtrate pipe) was used as external carbon source in case the SBRs run into carbon limitations during the test phase. Both chemicals are stored in IBC tanks placed on top of spill basins (Figure 9) and are dosed into the system by diaphragm pumps.

Figure 9: The chemical container in the middle of the construction work

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

The polymer station (Figure 10) can automatically prepare stock solutions of polymer product from both powder and liquid polymers. Stock solutions are matured with gentle mixing, stored, and pumped on demand at a concentration of 0,1% active matter into the flocculation tank by a dosing diaphragm pump. Polymer can also be dosed in the filtrate to improve TSS settleabilty in the SBRs. Powder polymers were used during the test and all polymer concentrations given in this report are expressed as mg-active polymer per L of wastewater.

Figure 10: Polymer station

The chemical container also contains a water buffer tank in order to ensure a stable supply of pressurized water to the plant. Acidic chemicals are also stored in this container together with the compressor for the high pressure cleaner, and the magnetic pumps used to feed the automatic chemical cleaning system.

Control cabinets and power boxes

The plant can be controlled both through the provided control cabinets in the filter container in Figure 11 or through the WWTP central control software with the programmed communication. Turbidity in influent and filtrate, treated flows, backwash times, dosing rates, sludge production, energy consumption, and water consumption were all logged for further data analysis.

Figure 11: Manual control panel in the microscreen plant at the Westewitz WWTP

2.1.3. Influent water characteristics

The influent quality to the microscreen plant after grid removal and sandtrap is similar to the inlet of the WWTP for total COD and Phosphorus. The TSS concentration into the microscreen (Table 1) was lower than in the influent to the WWTP (Table 3), but can be explained by the TSS-reductions obtained in the mechanical pre-treatment.

Table 3: Characteristics of the influent wastewater treated in the pilot plant. The turbidity values are hourly averages from the online sensors. The others are grab samples of the influent to the filter.

	Turbidity	TSS	COD-tot	COD-sol	TP
	(NTU)	(mg/l)	(mg O_2/l)	(mg O_2/l)	(mg/l)
Average	231	284	624	272	9,7
Min	31	120	197	162	3,7
Max	772	450	1148	353	16,1
n=	3555	21	170	8	115

2.2. Results

2.2.1. No chemicals

Filter performance

The turbidity reduction obtained without chemical addition observed (Figure 12) is around 35% for average influent characteristics (231 NTU, Table 3). For the most concentrated influent, the average reduction increased about 50% and for the most diluted influent only about 20% was removed.

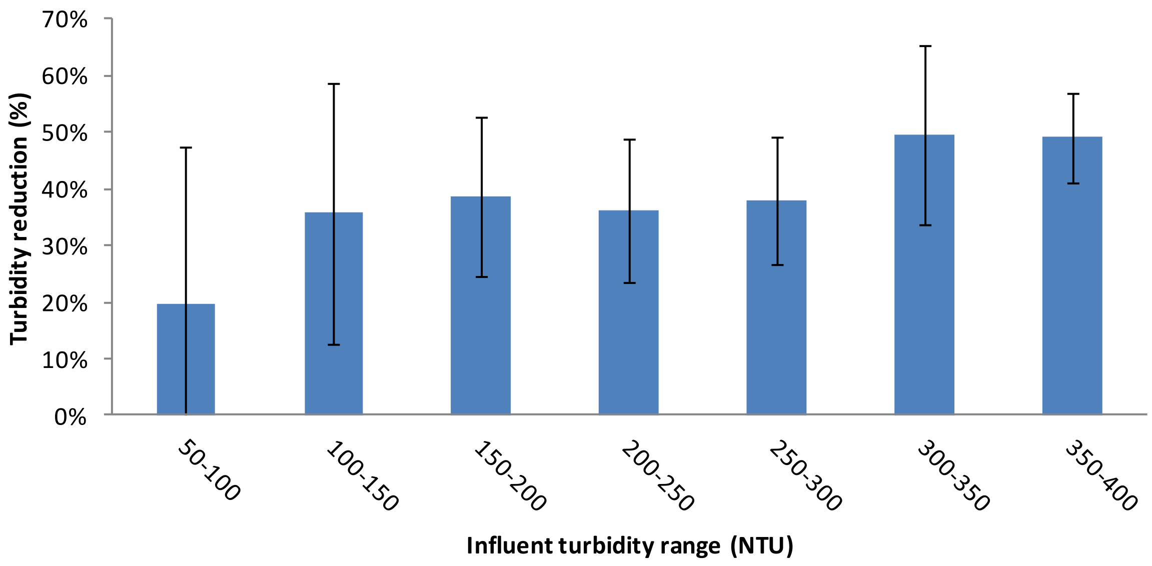

Figure 12: NTU-reduction in the pilot plant for different influent NTU-ranges without chemical addition

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

TSS collected from grab samples and turbidity data correlated well (Figure 76). The TSS-reduction during average conditions is about 50% without chemical addition (Figure 13), if the correlation factors presented in Appendix 1 are applied. For concentrated influent a 60% reduction could be obtained and reductions slightly above 40% were estimated for diluted water.

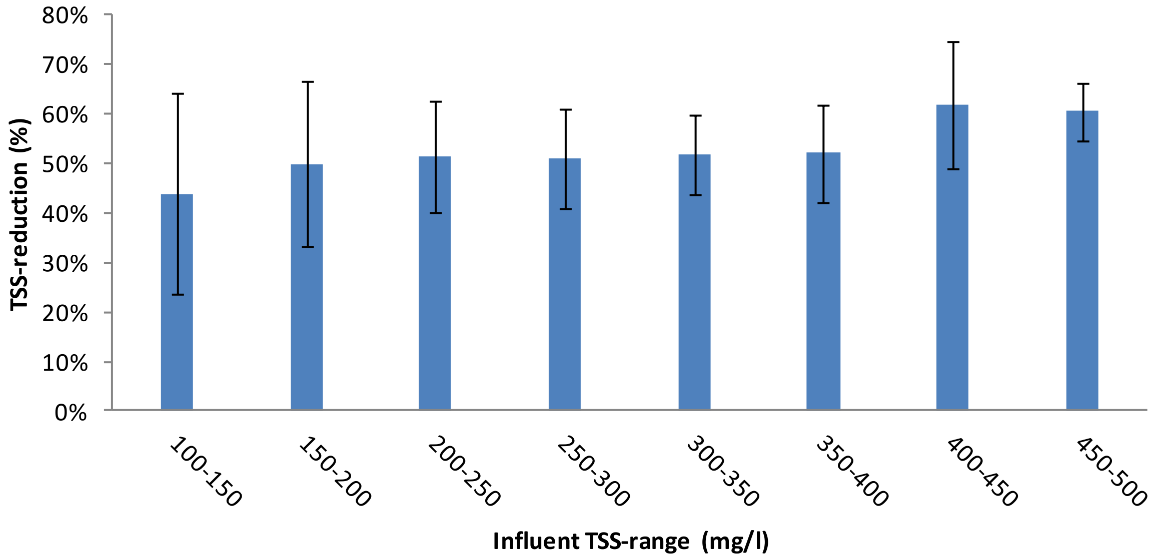

Figure 13: TSS-reduction for different influent TSS-ranges without chemical addition

Total COD analysed from grab samples and the logged turbidity data did not correlate well for high influent COD. The total COD reductions in Figure 14 are averages from grab samples collected during the trials. These results suggest a reduction of 20-25% during average conditions with peak reductions of 40-60% with more concentrated influents. The COD reductions recorded from grab samples are in the expected range for a water with about 50-60% particulate COD (Henze et al., 2008).

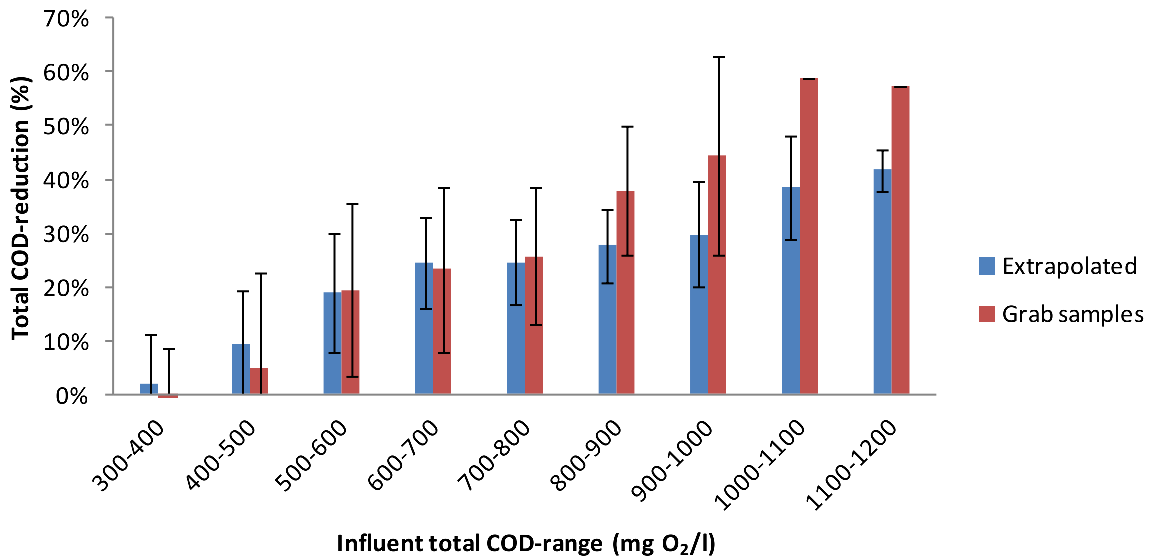

Figure 14: Total COD-reduction with no chemical addition

Total Phosphorus analysed from grab samples and the logged turbidity data did not correlate well. Total Phosphorus reduction for different influent TP-ranges measured from grab samples and extrapolated from turbidity-data are presented in Figure 15. The results suggest that reductions of up to 5-20%, depending on influent concentration, can be achieved (negative values expected to sampling errors). The obtained reductions are in the expected range for an influent with about 30% particulate P (Henze et al., 2008).

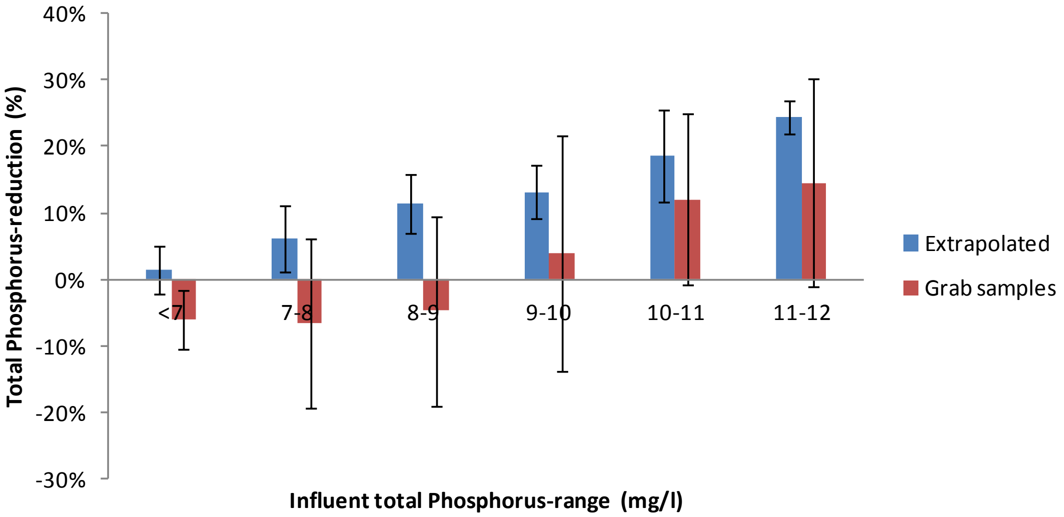

Figure 15: Reduction of total Phosphorus from without chemical addition for different influent TP-ranges

Sludge production and characteristics

The sludge production is correlated to the solids loading of the filter (

Figure 16). After chemical cleaning of the filter media the sludge flow was 1-3% of the influent flow, which is in the expected range during normal operation of the filter.

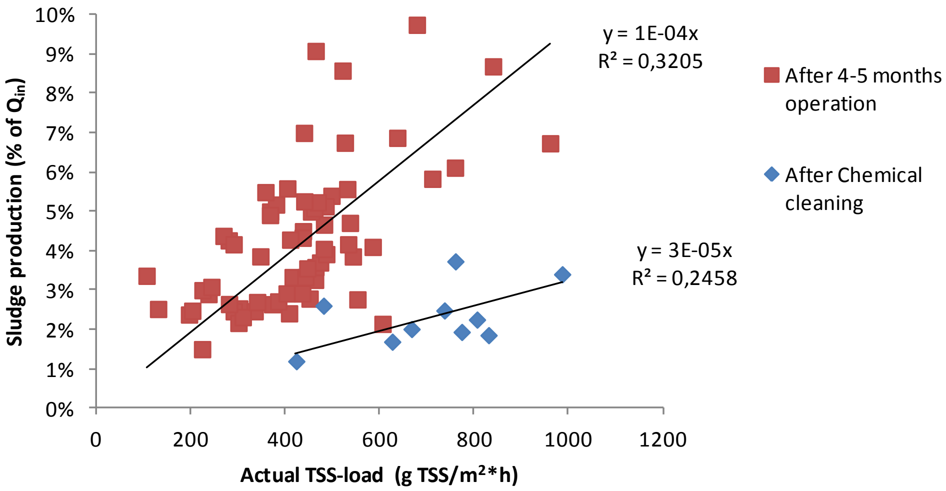

Figure 16: Sludge production in relation to TSS-load for the drumfilter at 7.5 bar BW-pressure for clean filter media (after chemical cleaning) and for clogged filter media after 5 months operation

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

The TS content in the sludge out of the drumfilter (Figure 17) shows a variation of 0.2% - 1.6% for similar influent characteristics. The average TS-content was 0.8% which is lower than the expected 1-4%, but still in the range that can be obtained in primary clarifier sludge . One reason to the lower TS could be the varying clogging degrees of the filter media. Other explanation could be low accuracy of the balance used for the analyses or difficulties to collect representative grab samples from one backwash event (sludge concentration is expected to vary during backwash).

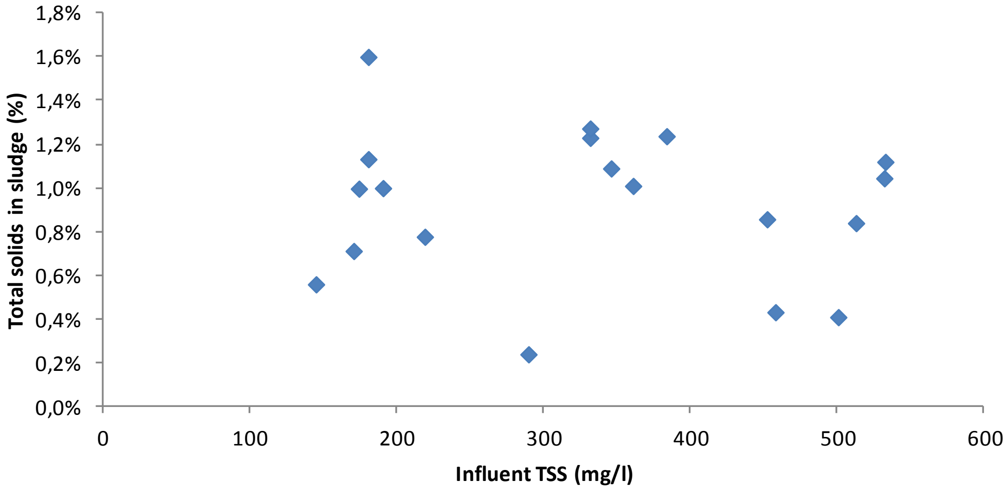

Figure 17: Total solids concentration in sludge out of drumfilter at corresponding influent TSS-concentrations without chemical dosing.

Energy demand

The energy demand required by the drumfilter electrical components (filter motor and backwash pump) during the operation prior and post chemical cleaning in Figure 18 suggests an average of 10 Wh/m3 when the filter is clean. Depending on the clogging degree of the filter, energy demand may be up to three times higher compared to a newly regenerated filter media after chemical cleaning.

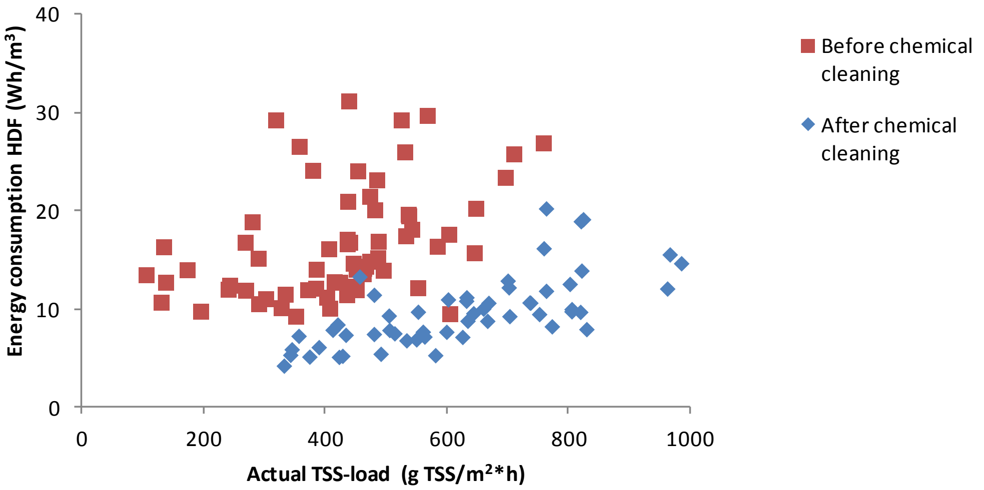

Figure 18: Drumfilter energy consumption at different loading conditions after 4-5 months operation without chemical cleaning and for a period right after chemical cleaning

Backwash frequency

The backwash frequency is the percentage of time during which the filter is in backwash and gives an indication of the % of the maximum capacity used to treat a certain TSS load. The results show that after 5 months operation without chemical cleaning, the backwash frequency is about three times higher compared to operation after chemical cleaning for the same solids load (Figure 19). Only 15% of the filter capacity was used during peak loading conditions observed.

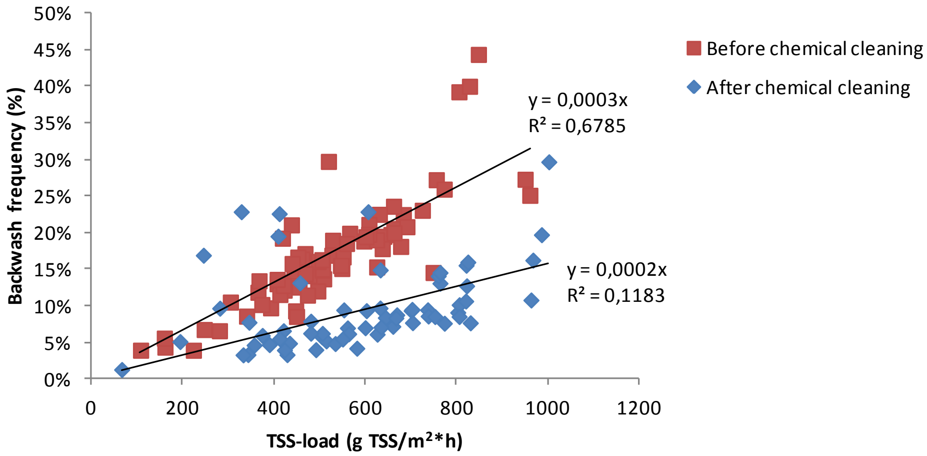

Figure 19: Actual solids loading and corresponding backwash frequency of the drumfilter before and after chemical cleaning.

2.2.2. Flocculation with polymer

Mixing speed and impact on flocculation process

The turbidity removal of the filter at different mixing speeds applied in the flocculation tank is seen in Figure 20. The data does not show any obvious improvement of the turbidity removal at any special mixing speed. Higher mixing speeds helped reducing the formation of a sludge layer on top of the flocculation tank.

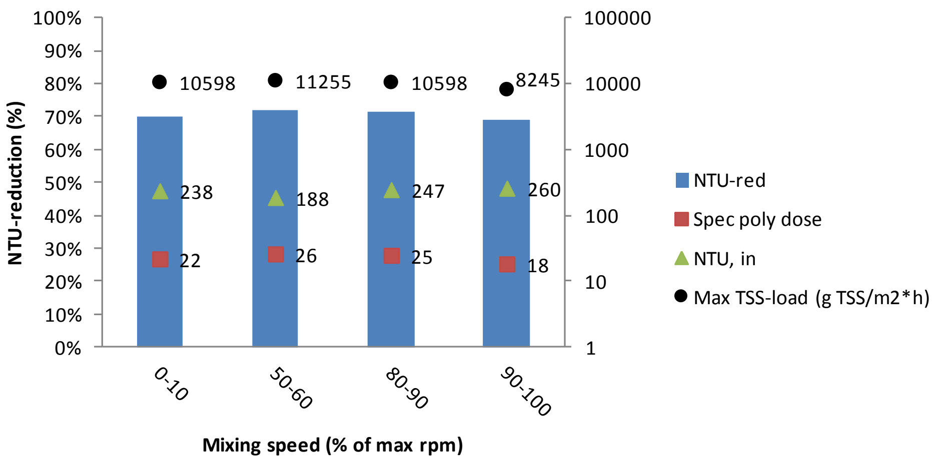

Figure 20: Effect of mixing speed adjustment on polymer dose and NTU-reduction.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Filter performance

Depending on the polymer dose and influent concentration, the turbidity reduction will be in the range of 55-90% (Figure 21). The results show that the higher the polymer dose, the better removal obtained. At average conditions turbidity removals of 65-70% can be obtained with a polymer dose of 4 mg/l.

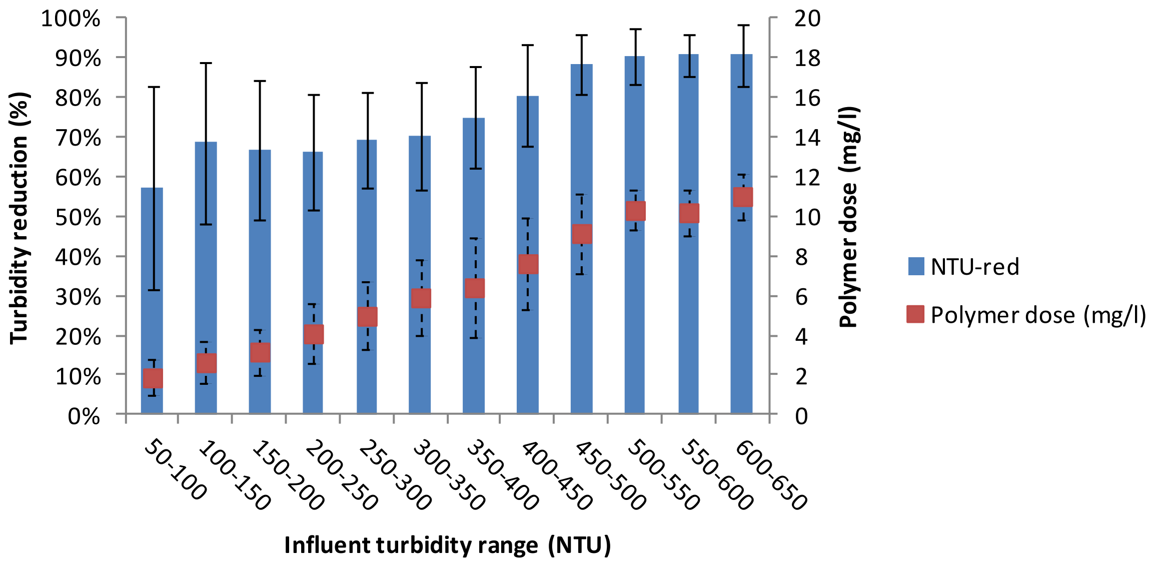

Figure 21: Turbidity reduction with polymer dosing applied.

Online turbidity data and TSS data analysed from grab samples correlated well. The estimated TSS-reduction calculated from correlation factors (Figure 22) suggests that 70-85% removals can be obtained with different degrees of polymer dose. At average conditions the TSS-reduction was 70% with a polymer dose of 4 mg/l. The average TSS removal without chemicals was on average 50%.

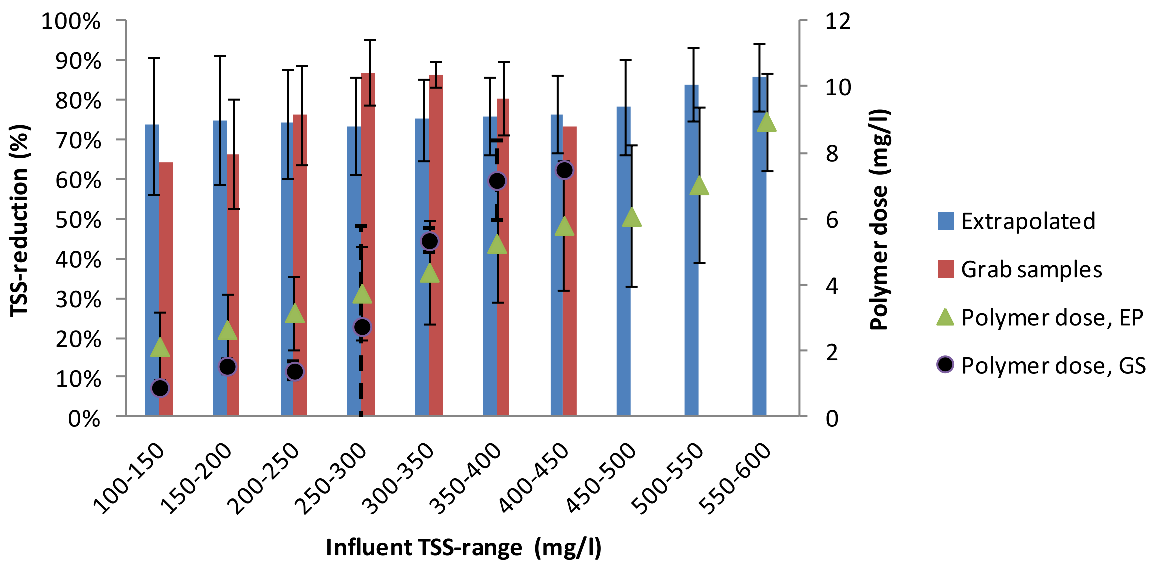

Figure 22: TSS-reduction with polymer dosing applied (estimated from turbidity correlations).

Grab samples and total COD extrapolated from turbidity data correlated well when operating with flocculation during the test period and suggests that on-line turbidity measurements can be used in order to control chemical dosing and target a certain COD extraction (Figure 23). The data suggests that depending on the polymer dose, the reduction could be in the range of 30-80%. As for both TSS and turbidity, the higher polymer dose applied the better removal obtained. At average conditions the total COD-reduction was 45-50%. Increasing the TSS removal efficiencies with polymer doubled the COD extraction efficiency from 20-25% (Figure 14) to 45-50% (Figure 23).

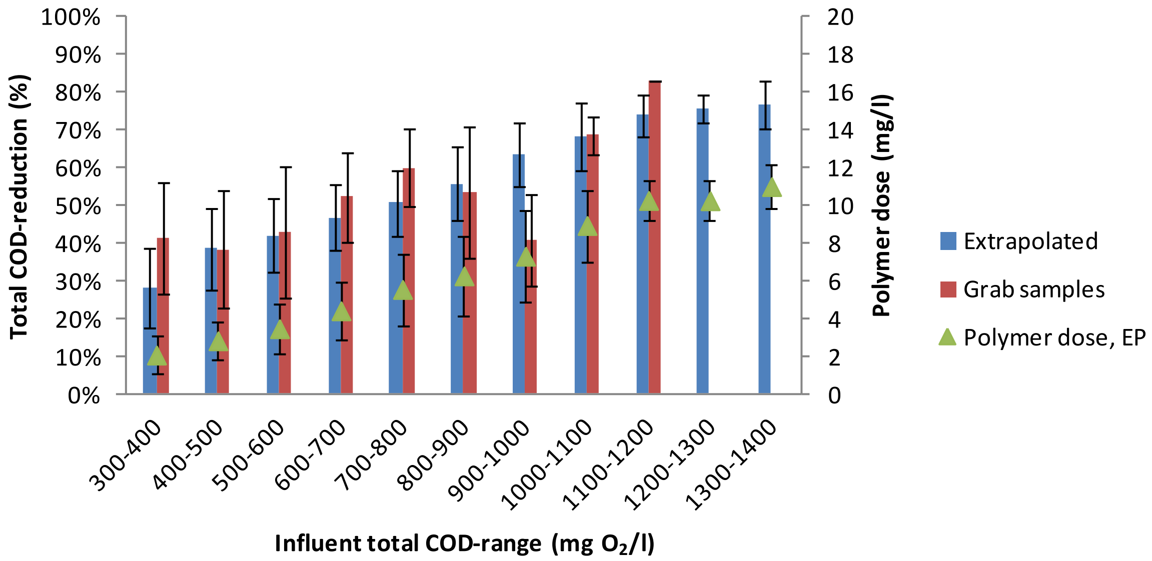

Figure 23: Total COD-reduction with polymer dosing applied (correlated from turbidity values).

The results obtained from grab samples (Figure 24) show ca. 25% TP-reduction at average conditions, which is in line of what can be expected for water with 30% of the TP in particulate form.

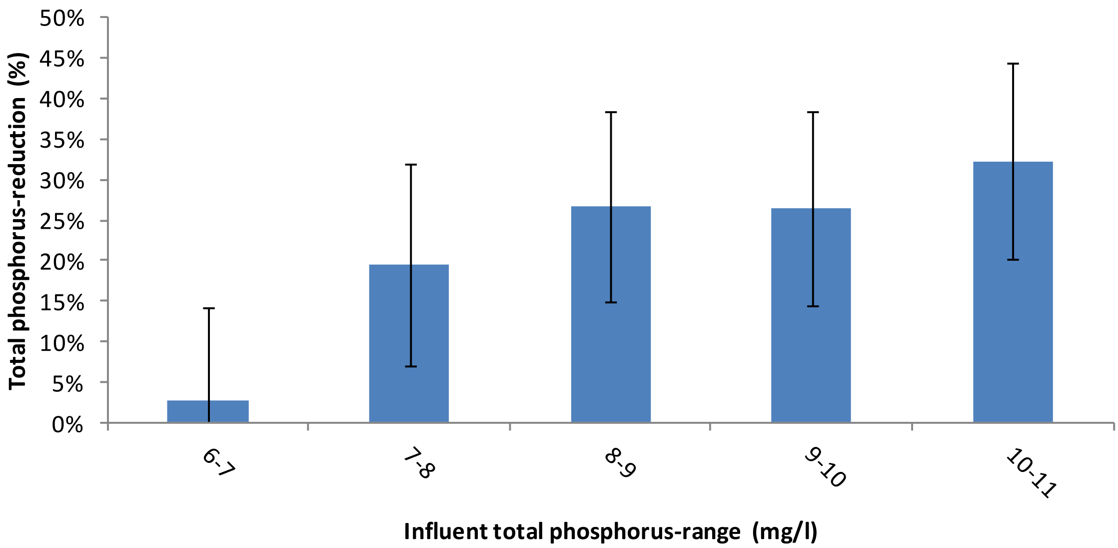

Figure 24: Total phosphorus-reduction from grab samples collected while flocculant was dosed

The project “Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration” (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Sludge production and characteristics

The sludge production when applying flocculation with clean filter media and with filter media at varying clogging degree is shown in Figure 25. After chemical cleaning, the sludge flow range was 1-2% of the influent flow, as expected. The results showing sludge productions of up to 30-40% of the influent flow were obtained 8-9 months after chemical cleaning. Media clogging led to very low capacities resulting in high energy demand and high sludge production during the trials.

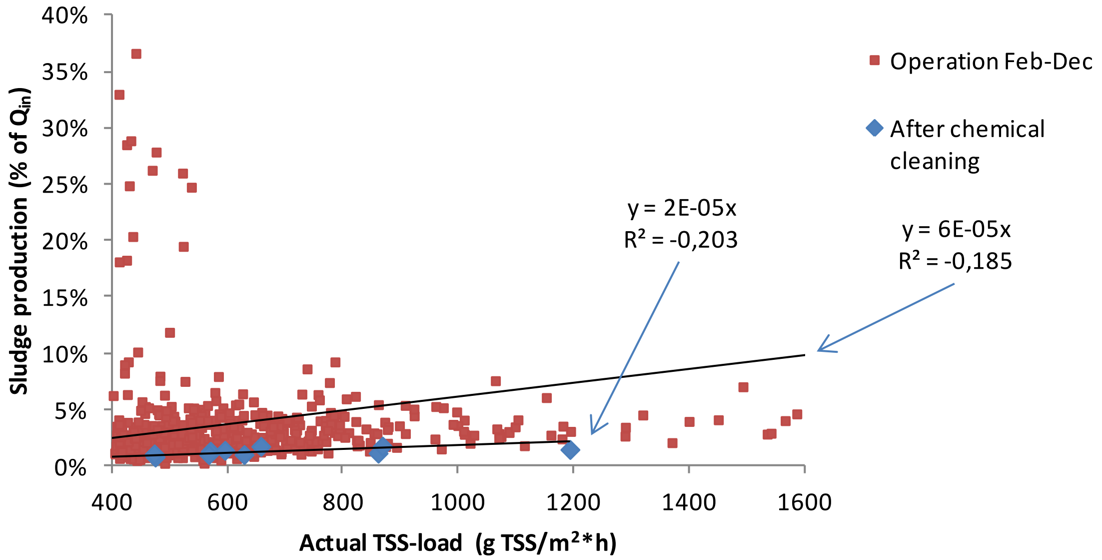

Figure 25: Sludge production as percentage of influent flow in relation to actual TSS-load for operation with chemically cleaned filter media and at varying clogging degree with flocculation applied.

The average TS-content in the sludge out from the drumfilter (Figure 26) was 1.4%. However, the variation is high and does not correlate well with the influent TSS. Maximum TS-concentrations during the test period was 2.5%, obtained when running the filter with 20% less water-consuming nozzles at 8 bar backwash and 5-8 seconds shorter backwash sequences. It was not possible to run the filter at these conditions as the 2.5% sludge was too concentrated to flow out by gravity. This test eventually resulted in a blockage of the sludge pipe, which required high pressure flushing to get the plant back into operation again.

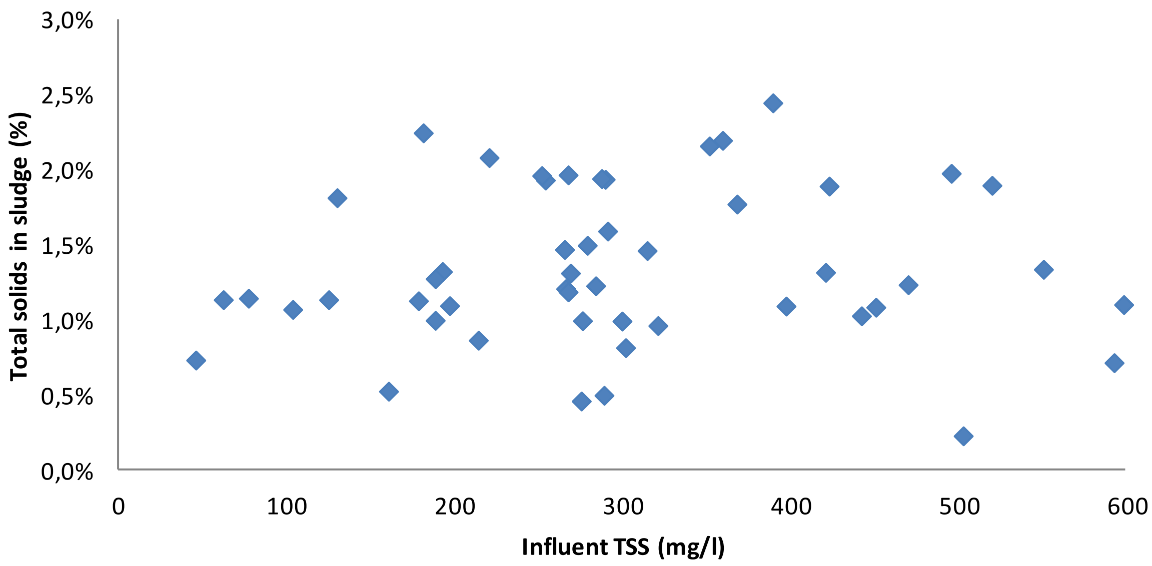

Figure 26: Total solids concentration in sludge out of drumfilter at corresponding influent TSS with flocculation

Energy demand

The energy demand of the plant in Figure 27 shows that the equipment needed for the flocculation was significantly exceeding the energy demand of the filter for the flow range tested in Westewitz. The data also suggest that the energy demand per m3 treated water decreased when increasing the influent flow, which indicates that the optimum energy demand was not reached at this site due to the limited flow available. The minimum energy demand for the whole plant with a clean filter was about 45 Wh/m3.

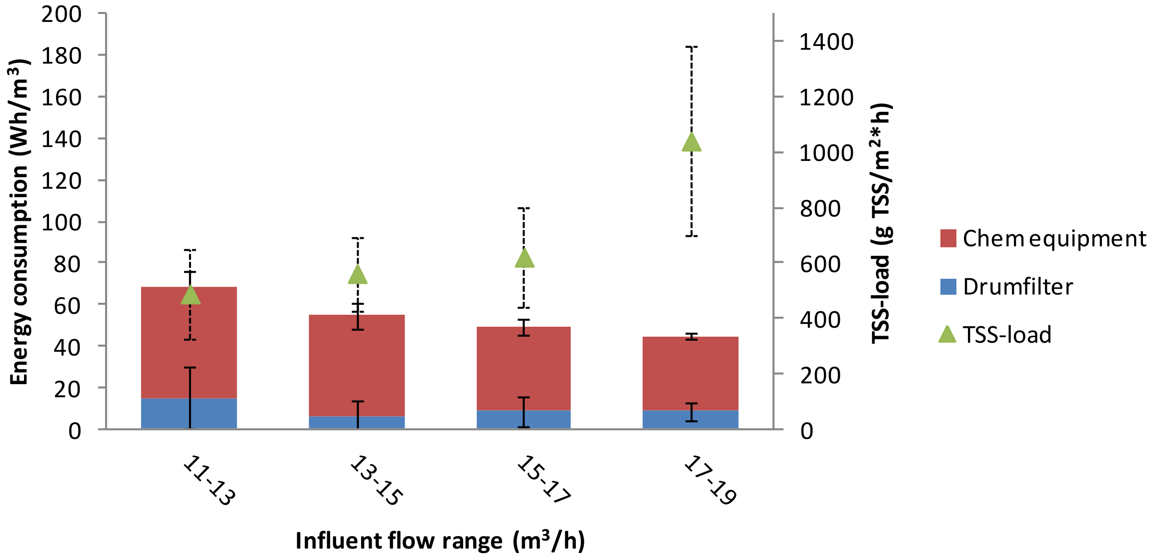

Figure 27: Energy demand with flocculation applied for the chemical equipment and the drumfilter after chemical cleaning.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Energy consumption data with the heavily clogged filter (9 months without chemical cleaning) is shown in Figure 28 and suggests that the drumfilter energy demand was 3-8 times higher than necessary if the filter is not clean.

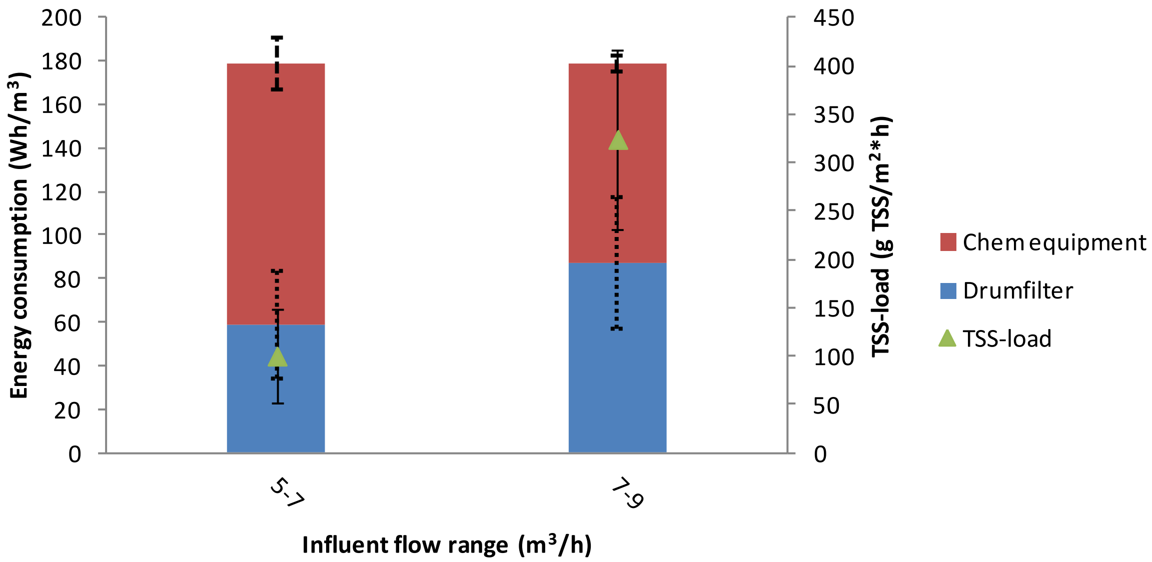

Figure 28: Energy demand with flocculation applied for chemical equipment and the drumfilter after 8-9 months operation without chemical cleaning.

Backwash frequencies

The solids loading and backwash frequencies for the drumfilter when polymer is added are shown in Figure 29. These results suggests up to 9 times higher backwash frequency before (4-5 months operation) chemical cleaning for the same polymer dose. The clean filter utilized only 5-10% of its maximum capacity for the peak loads observed.

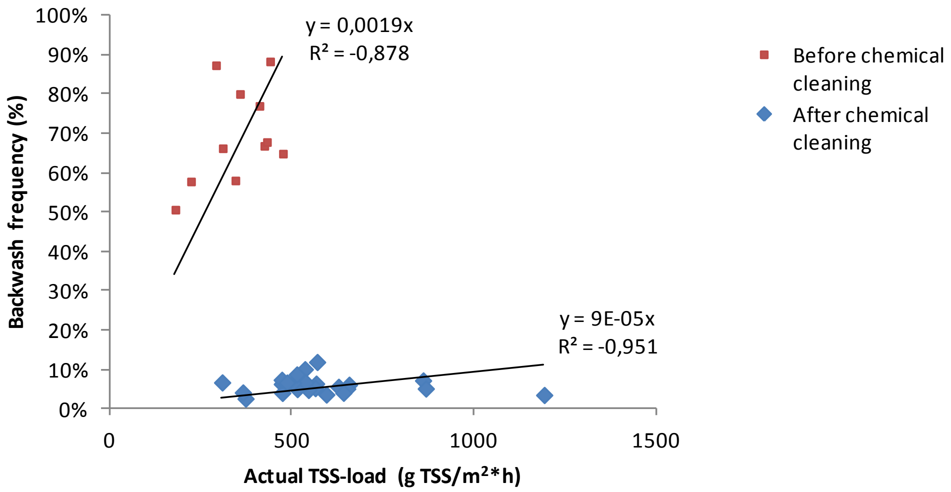

Figure 29: Solids loading onto the drumfilter and corresponding backwash frequencies for the same specific polymer dosing before and after chemical cleaning

2.2.3. Coagulation and flocculation

Dosing strategies

Two dosing strategies were tested in Westewitz when coagulation and flocculation was applied: flow-proportional and effluent turbidity controlled dosing. Both strategies were hard to get to work well due to the irregular inflow to the filter (Figure 30). The main issue was that every time the flow went down to 0m3/h, which happened regularly, the water in the coagulation tank and in the influent pipe went back into the pumping pit (a volume of about 1 m3). Sometimes this happened several times every hour. As a consequence, a constant coagulant dose was difficult to maintain in the plant.

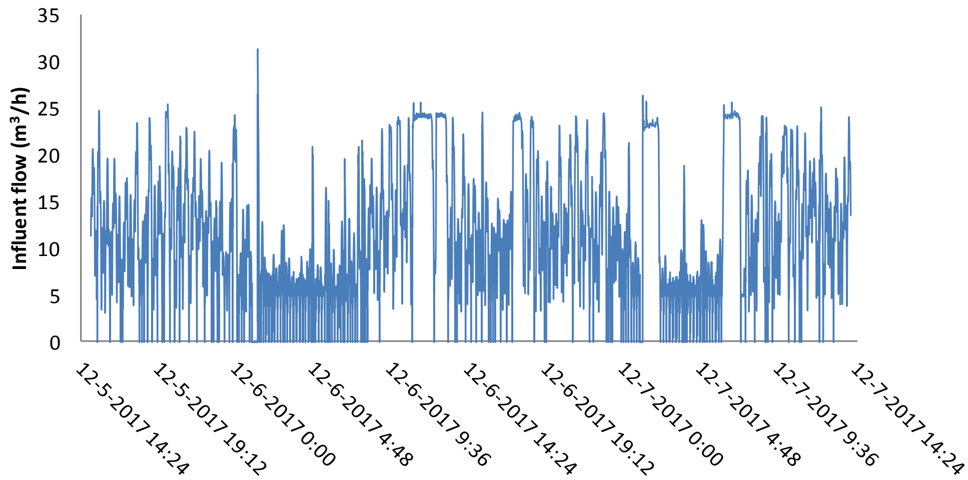

Figure 30: Inflow pattern during an operation period with effluent turbidity dosing control. Every time the inflow was 0m^3/h, the coagulated water in the tank was drained back to the influent pit

The results from the effluent turbidity controlled dosing can be seen in Figure 31. Two set points were tested, 10 and 50 NTU, and in both cases it was possible to achieve the target value in average even IF the influent turbidity and the influent flow varied.

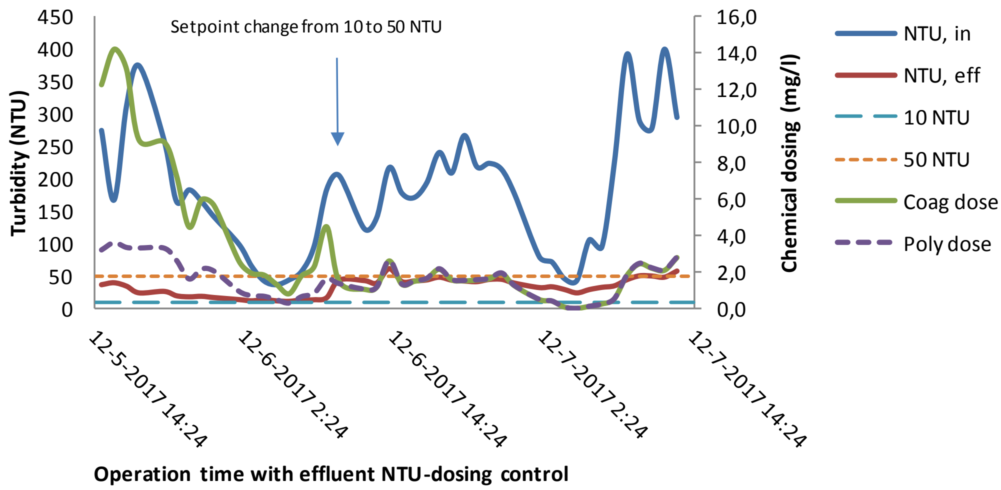

Figure 31: Hourly average influent and effluent turbidity and chemical doses during a period with effluent NTU-controlled dosing.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Filter performance

The dose of coagulant upstream the filter yielded a higher turbidity reduction than when only polymer was added for flocculation purposes (Figure 32 and Figure 21). As a matter of fact, the same or higher target turbidity could be achieved with 2-3 times lower polymer dose. The dose of coagulant did not seem to impact the turbidity removals significantly.

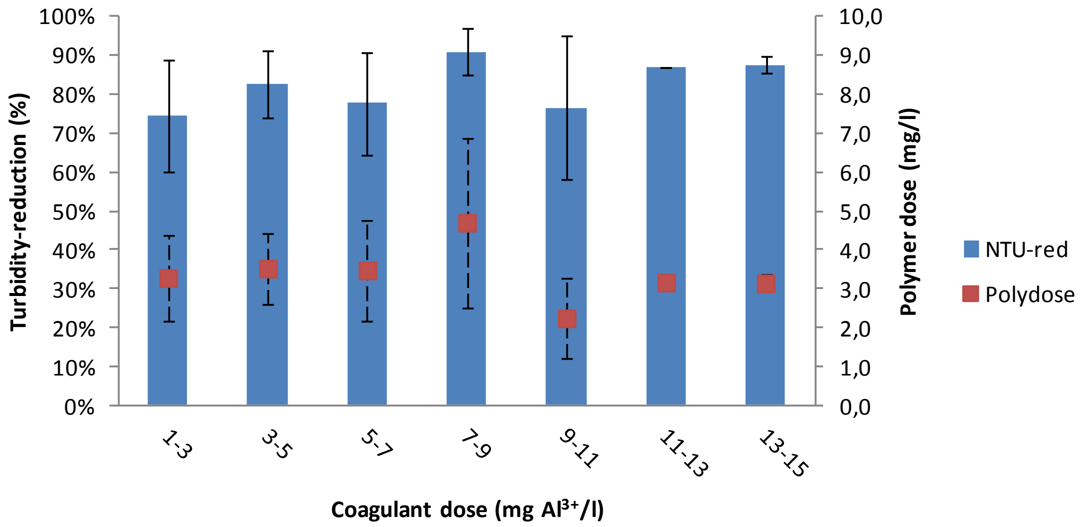

Figure 32: Turbidity reduction with coagulation and flocculation applied

TSS removals above 90% can be estimated from applying the correlation factors defined in Appendix 1. Again, both the polymer and coagulant dose do not seem to correlate with the estimated removals. The cost of dosing 1 mg-Al^{3+} is about 1.5-2 times the cost of dosing 1 mg of polymer, so the actual benefit of dosing coagulant is questionable.

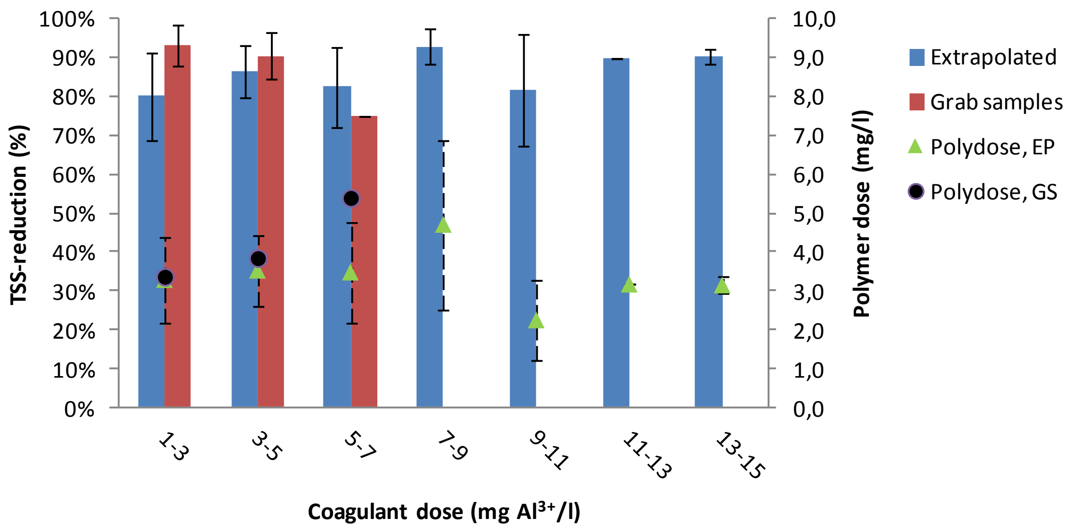

Figure 33: TSS-reduction with coagulation and flocculation applied.

The COD removal ranged between 50 and 70%, this is 0-20% more than with just polymer addition and 30-50% more than without chemical addition. No correlations could be drawn with the coagulant or the polymer dosed.

The estimated COD removal from turbidity correlations matched quite well the range measured with grab sampling (Figure 34), suggesting that the given correlations could be used in order to tune the COD extraction in the primary filtration stage by adjusting the chemical dose in the 2-stage chemical pre-treatment system. Unfortunately, doses and COD removals are not correlated, making such feature difficult to implement.

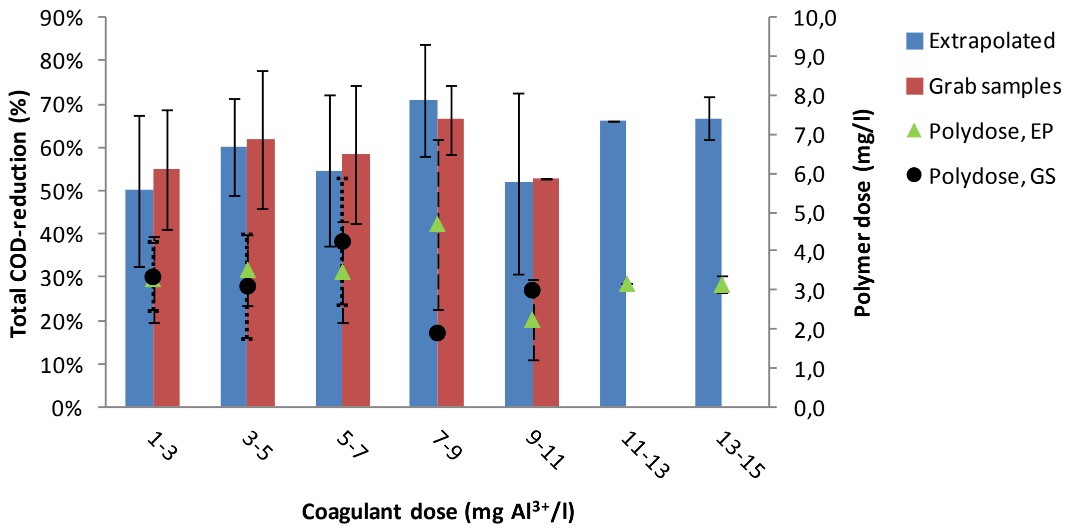

Figure 34: Total COD-reduction with coagulation and flocculation applied

The influent turbidity meter did not capture the chemical TSS generation associated with the dosing of coagulant. The grab samples suggest that a TP-reduction of 40-80% was obtainable with the tested doses (Figure 35).

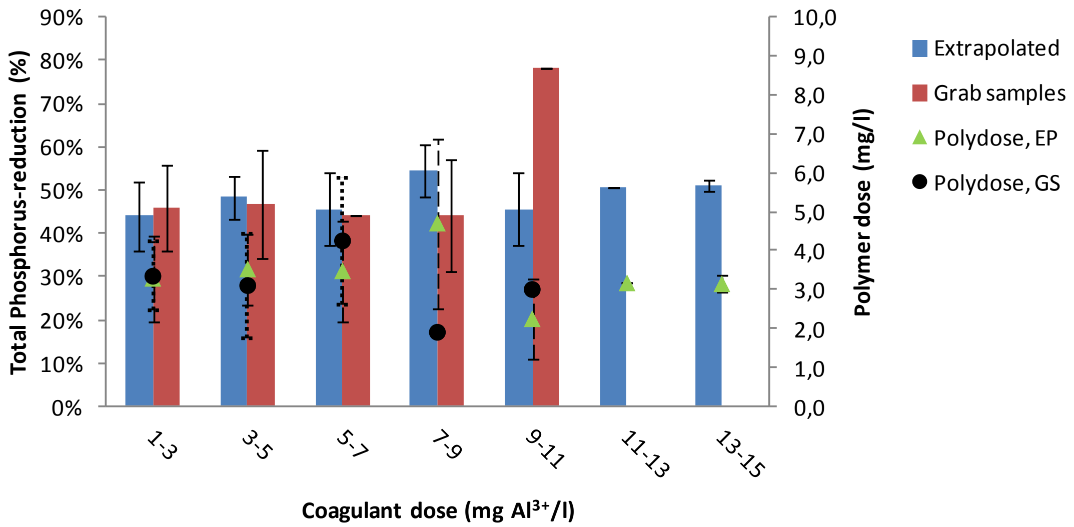

Figure 35: Total Phosphorus-removal from grab samples and turbidity correlated data with coagulation & flocculation applied.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Sludge production and characteristics

Coagulant dosing had an impact on the hydraulic capacity of the system and the clogging degree of the media. Given the same SS load into the filtration system, a clogged filter operated with coagulant and polymer dosing required ca. 5-6 times more water before than after chemical cleaning. This figure highlights the importance of filter maintenance when attempting dual chemical dosing in chemically-enhanced primary filtration.

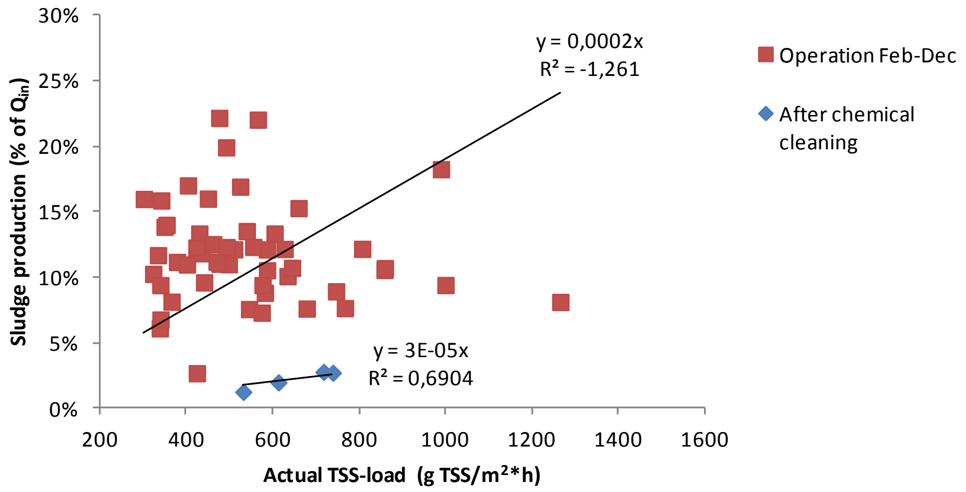

Figure 36: Sludge production as percentage of influent flow in relation to TSS-load for operation with chemically cleaned filter media and at varying clogging degree. Data collected with both coagulant and polymer dosing

The increased production of sludge due to the higher clogging degree also had a clear impact on the sludge thickness, which was 2-3 times lower than observed without chemical or with polymer dosing (Figure 38). The dispersion of TS dryness in the sludge for the same influent water characteristics was higher than for any of the other dosing scenarios studied here.

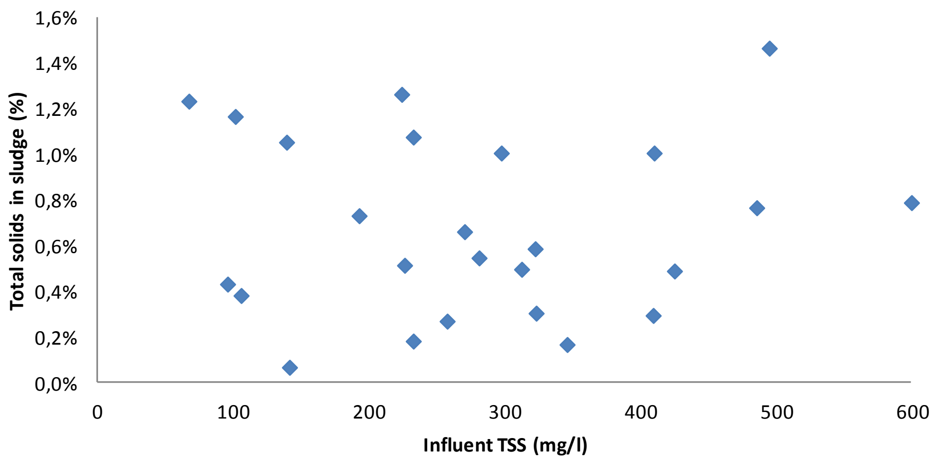

Figure 37: TS concentration in sludge out of drumfilter for corresponding influent TSS-concentrations with coagulation and flocculation applied. Average TS concentration was 0.7%.

Energy demand

The energy demand of the system shortly after chemical cleaning with both coagulation and flocculation under operation did not differ much from any of the other dosing scenarios considered during the pilot and the filter itself was a minor contributor to the energy consumption of the plant.

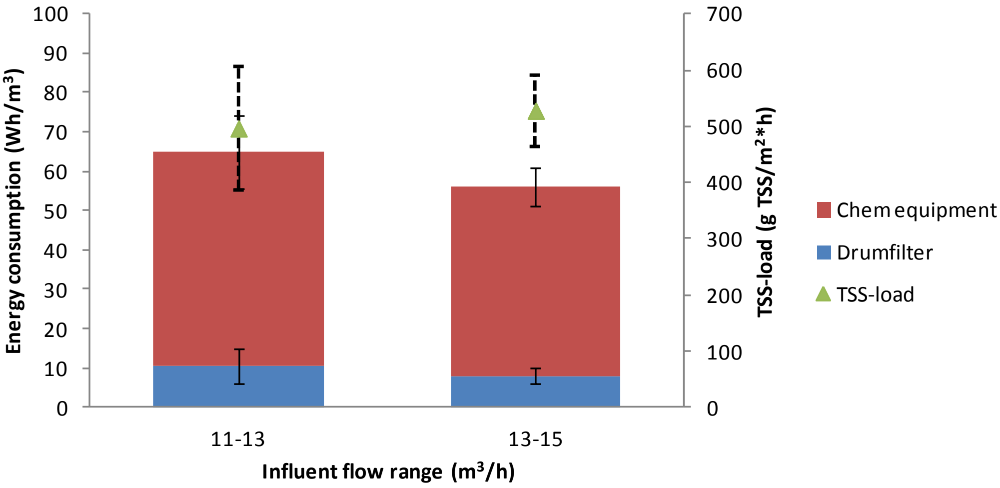

Figure 38: Energy demand for chemical equipment and the drumfilter during operation with coagulation and flocculation one week after chemical cleaning. The energy demand in Wh/m^3 treated water from the chemical equipment decreases with increasing flow.

Solids loading

The actual solids loading and corresponding backwash frequencies for the drumfilter when coagulant and polymer is added are shown in Figure 39. Coagulant dosed clogged the filter media faster and yielded 6-10 times higher backwash frequencies compared to the case when only polymer was dosed.

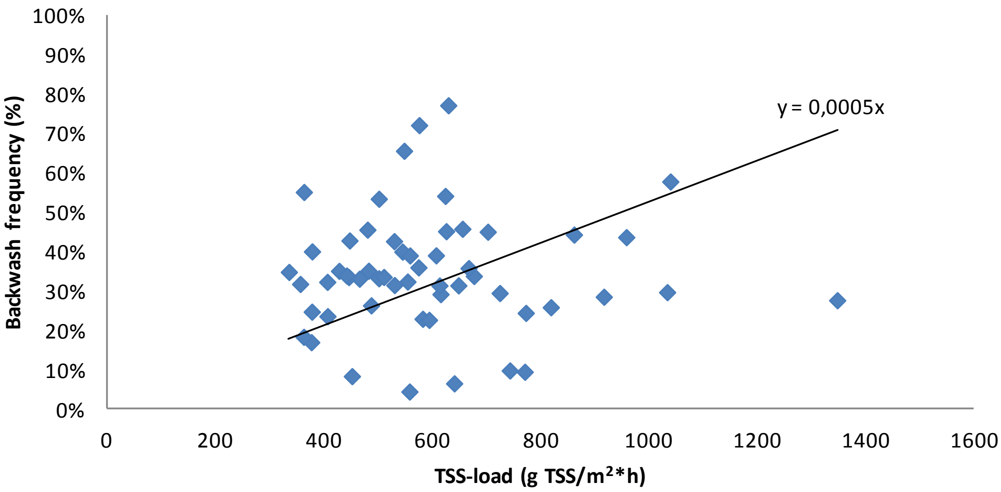

Figure 39: Solids loading including TSS produced by coagulant addition onto the drumfilter and corresponding backwash frequencies when operating with coagulation and flocculation.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

2.2.4. Maintenance needs and operation issues

Filter media

Chemical cleaning with HCl and NaClO were performed the 22nd of February 2017 and 4-5th December 2017. High pressure cleaning events at 80 bars were performed bi-monthly. No filter panels were changed during the reported operational period.

Taking as reference the chemical cleaning event in February 2017, it can be observed how the energy consumption of the drumfilter increases steadily over time due to clogging of the filter media (Figure 40). The energy consumption in November was 7 times higher than after chemical cleaning in February, even for substantially lower TSS loads. Data from October and November were only acquired during night operation which explains the low TSS-load during those months.

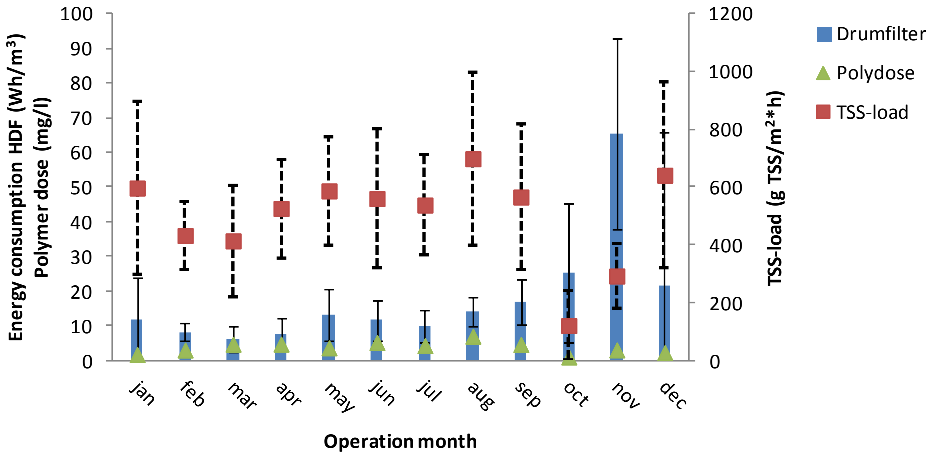

Figure 40: Drumfilter energy demand with flocculation applied.

The effectiveness of the chemical cleaning event in December 2017 was quantified in Figure 41. The media had been 5 months in operation without chemical pre-treatment prior to the chemical clean. As seen, the filter required to be washed 50% less time after chemical clean was performed for similar TSS loading. 50% less washing time extrapolates to 50% less energy consumption and 50% less water required to wash off the solids retained by the filter media, resulting in a thicker sludge.

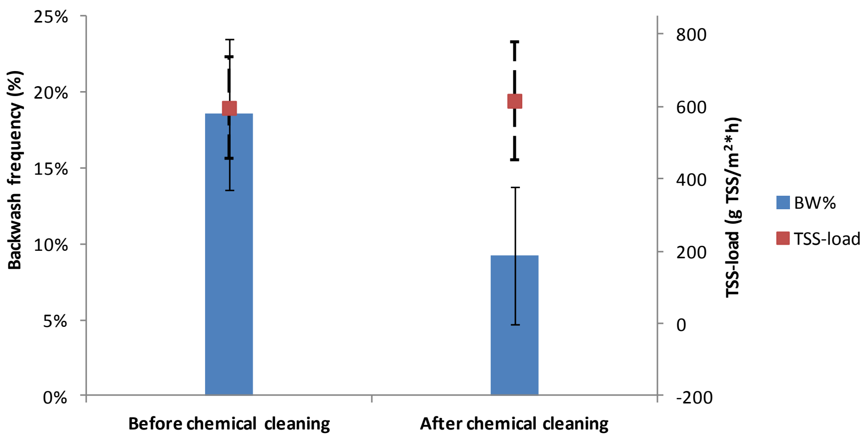

Figure 41: Effect of chemical cleaning event on filter performance

BW-pump and self-cleaning strainer

The self-cleaning strainer was installed to prevent the nozzles from clogging by particles from the filtrate, which was used for backwash throughout the pilot study. The system proved to work well and no manual cleanings of the system were required. The strainer impacted the backwash system as it required 2 bar for its self-cleaning procedure. Long term tests with lower backwash pressures (5-6 bar) in the drumfilter resulted in operation issues due to activation of the dry running protection of the backwash, which stopped the whole filtration plant.

In Figure 42 it is possible to see how the backwash of the self-cleaning strainer affects the drumfilter backwash pressure which decreases down to 1.5-2 bars when the cleaning process is initiated.

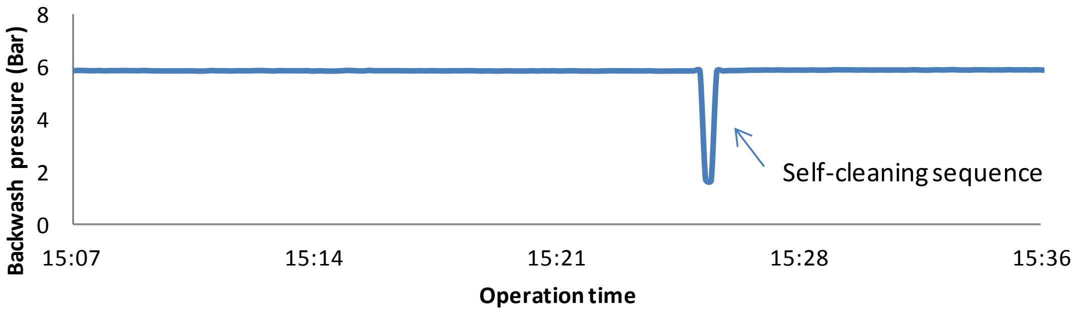

Figure 42: Backwash pressure drop during the self-cleaning sequence of the self-cleaning strainer.

The BW-pump was changed on the 19th September 2017 after one year of operation with filtrate. However, the operation data indicates that the first BW-pump was still in good condition giving 7.3 bars at the time of the change (Figure 43).

Most of the data collected with backwash pressure below 7 bars relates to operation with coagulation and flocculation. It is suspected that the self-cleaning strainer is negatively affected by the coagulant, probably due to precipitation of residual aluminium.

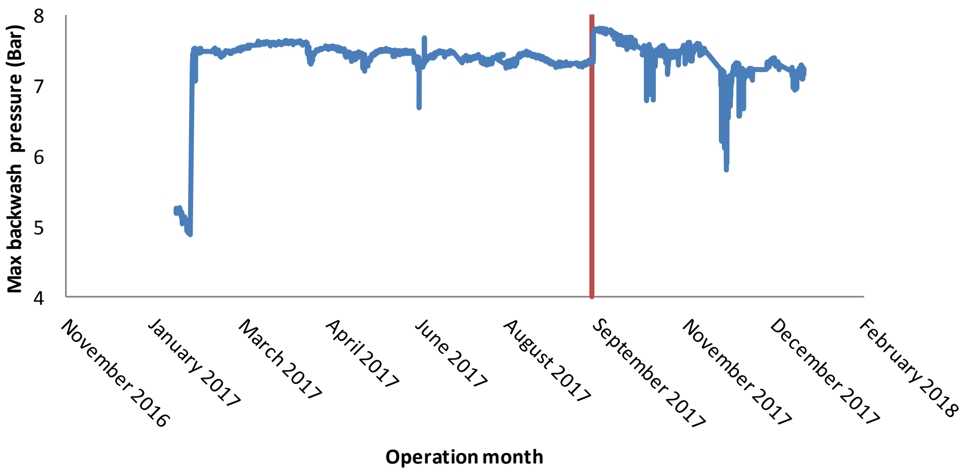

Figure 43: Backwash pressures from January 2017 until January 2018. The red line shows the change of backwash pump.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Nozzles

Hydrotech standard drumfilter nozzles were used during most of the operation time except from 2 days, where Hydrotech standard Discfilter nozzles (using 30% less water) were used in a test to increase the TS-content in the sludge. Nozzle clogging was never observed during operation and very limited maintenance has been needed due to the well-functioning self-cleaning strainer. Operation with Discfilter nozzles yielded thicker sludge, that clogged the backwash effluent pipe. Therefore, conventional drumfilter nozzles were re-installed.

Automated high-pressure cleaning

The automated high pressure cleaning system consists of a block with 2 nozzles mounted on a rail above the length of the drum. During high pressure backwash, the block slides slowly along the rail, while the drum rotates and the high pressure nozzles spray water at 80 bar. The moving block with the spraying arms did not work properly and got stuck in a specific position until it was manually forced to move. The problem was solved by installing a couple of spacers to lift the block into the right position.

Automated chemical cleaning

The chemical skid supplied for automated cleaning worked fine, but has only been used twice for chemical cleaning during the operation period. The only issue experienced with the chemical cleaning was clogging of chemical spraying nozzles by biofilm. This can be avoided by removing the nozzles after the chemical cleaning has been performed and keep them stored until next chemical cleaning session or flushing the nozzles regularly and force biocide flow through them. This is especially advised in cases like this with 10 months in between the chemical cleanings. Prior to reinstalling the nozzles for the chemical cleaning it is advised to flush the chemical spraying system with tap water to properly rinse the spraying bars.

Online sensors

No issues have been experienced during the operation period. The included wiper keeps the glass window where the sensor is placed clean without any manual maintenance for at least 2-3 months. Except from the maintenance needs listed in the operation manual for the instrument it is advised to clean the sensor window with glass detergent once every 1-2 months to secure proper operation, especially when using turbidity controlled chemical dosing.

Mixers

No issues or maintenance needs regarding the mixers have been identified during the operation period.

Polymer station

Cleaning of the preparation and storage tanks in the polymer station is advised every 2-3 months to remove old polymer that has been stuck to the mixers and walls and bottoms of the tanks. This is done to secure a properly mixed polymer and also to avoid large flakes of polymer-pieces clogging either suction strainers or non-return valves in the polymer dosing pump. Calibration of the powder dosing may be required on a long term basis; a need for this can be identified by controlling the set polymer concentration in relation to the TS-content in the prepared polymer in the storage tank.

Dosing pumps

No issues have been experienced with the dosing pumps. Maintenance needs during the operation time have been restricted to calibration of the dosing flows, which is necessary if changing the polymer concentration in the stock polymer solution or changing to a different polymer or coagulant. The non-return valves in the polymer dosing pump should be cleaned twice a year to avoid clogging.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

3. Primary treatment with Hydrotech discfilter at Sjölunda WWTP

3.1. Introduction to the site

The Sjölunda WWTP started-up in 1963 and serves 300000 inhabitants from the south of Sweden (Malmö, Burlöv, Lomma, Staffanstorp, and Svedala). The wastewater is led into the plant by several pumping stations located downstream each catchment area. The plant has BOD7 (<12 mg/L), TP (<0.3 mg-P/L) and TN (<10 mg-N/L) requirements, all of them have to be measured as monthly average. The main challenges for the future of the WWTP are the steep increase in population of the Malmö area and more stringent regulations.

The main treatment line (Figure 44) features primary treatment with 3 mm screens, grit removal, and primary clarifiers. Coagulant is added in the grit chamber for P pre-precipitation. The biological treatment consists of four High Loaded Activated Sludge (HRAS) systems followed by trickling filters and post-denitrification moving-bed biofilm reactors for complete N removal (refer to D2.2 for details). Tertiary solids are removed by flotation. Additional coagulant can be added into the dissolved air flotation units if required.

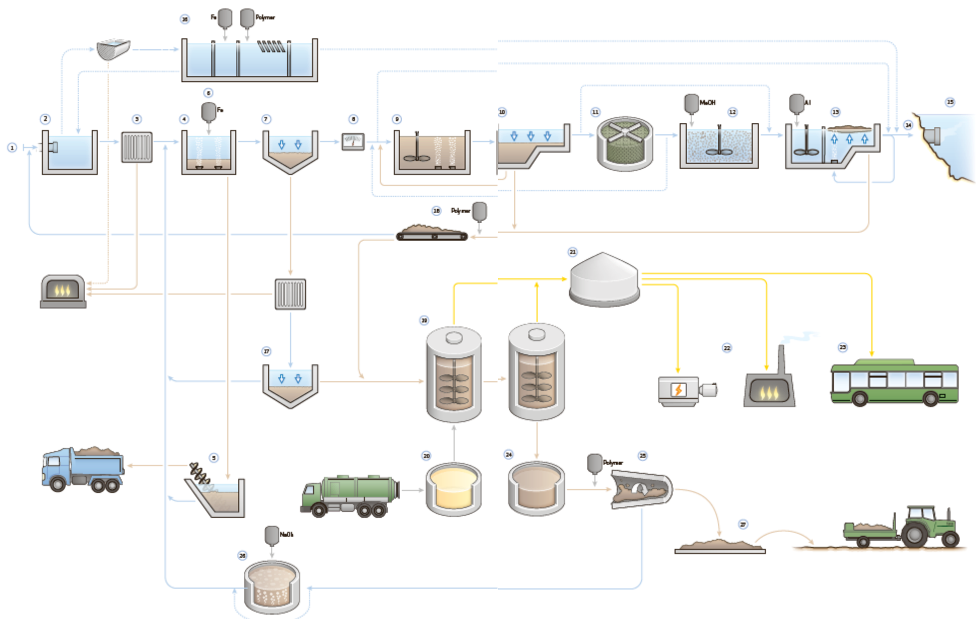

Figure 44: Wastewater treatment train in the Sjölunda WWTP (Figure taken from VA SYD's website)

3.2. Pilot setup

The POWERSTEP pilot plant at Sjölunda WWTP (Case Study 2) included a Discfilter to explore the limits of this technology with the objective to maximize hydraulic throughput in a minimal footprint. The test unit was installed on-site and was commissioned in March 2017 and was running until 13 November 2017 when it was replaced with a drumfilter. The water to treat was pumped directly from the effluent of the grit chamber. Pipes were installed underground all the way to a test tent belonging to the WWTP. The tent has heating, power and technical water supply, which helped to shorten the time required for the construction of the microscreen plant (Figure 46 and Figure 45).

Figure 45: Exterior and interior of the pilot hall

Figure 46: Grit chamber effluent (left), Crane for influent pump and influent turbidity sensor in the middle and pipe work towards the Discfilter plant (right)

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

The layout for the pilot plant with the Discfilter in CS2 can be seen in Figure 47. The pumped wastewater was led directly to a Drumfilter equipped with a 1 mm mesh in order to protect the Discfilter equipment from residual sand and grit, and to ensure robust operation throughout a long period of time. Coagulation and flocculation were performed on demand in the same fashion as presented in CS1. The flocculated primary wastewater is led by gravity into the influent of a HSF2200-C Discfilter, which was adapted to the treatment of water with high suspended solids concentrations. A 100 µm cloth was selected in order to ensure a high treatment capacity. The filter was also equipped with automatic high pressure and chemical cleaning. Filtrate from the Discfilter flew by gravity into an effluent buffer tank for further pumping back to the primary treatment of the WWTP. The sludge from the Drumfilter and the Discfilter flew by gravity into a common sludge tank for further pumping to thickening and dewatering treatment stages at the WWTP.

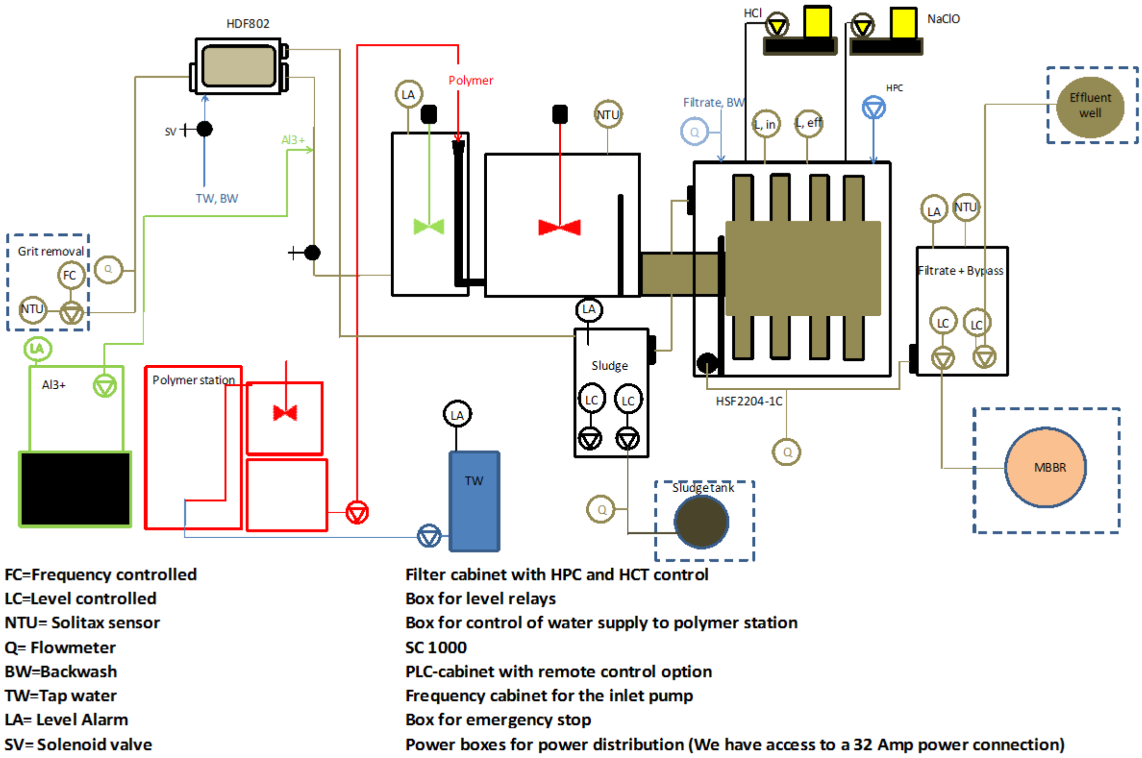

Figure 47: Layout inside the experimental carp at the POWERSTEP plant

The polymer station is analogous to the one presented for CS1 (powder polymer was used here as well) and a tap water buffer tank was also used in order to ensure stable water pressures during polymer preparation. Coagulant (Al-based) was stored in an IBC tank placed over a spill pallet.

Continuous measurement and logging of turbidity in the influent and the effluent of the microscreen plant were performed with Solitax SC sensors from Hach. The influent sensor was located in the pumping pit and was also used for control of the turbidity-proportional dosing of chemicals. The effluent sensor was mainly used for control of the filtration performance, but al-so for dosing control during tests performed to obtain a steady effluent quality. Both sensors were connected to a SC 1000 control unit from Hach for data interpretation and further trans-mission to a PLC. Turbidity data was used to estimate the TSS, COD and TP removal via correlation factors calculated by comparing online data to data obtained by analyzing TSS, COD, and TP in grab samples.

The plant was controlled through the control cabinets seen in Figure 45. Turbidities in influent, effluent from the flocculation tank, and filtrate, treated flows, backwash frequencies, dosing rates, sludge production, energy and water consumption has been logged for data analysis. Performances and alarms were monitored online through the installed GSM module.

3.3. Influent waste water characteristics

The characteristics of the influent to Sjölunda WWTP prior to mechanical treatment (Table 4) are expected to be significantly lower for COD and phosphorus compared to the grab sample results of the influent to the POWERSTEP pilot plant (Table 5). The explanation to this is that there is an internal return load at the WWTP which goes back to the primary treatment which is not affecting the concentrations measured at the plant influent sample point. In spite of the internal loads, the wastewater treated by the pilot plant described here could be classified as medium-low strength, as in the Westewitz WWTP case.

Table 4: Characteristics of the raw waste water influent to Sjölunda WWTP in 2015 excluding internal loading. The concentrations represent yearly averages.

BOD_7	COD-tot	TP	TN
(mg O_2/l)	(mg O_2/l)	(mg/l)	(mg/l)
224	466	4.4	40

Table 5: Characteristics of the influent waste water treated in the pilot plant. Grab samples were collected at the end of the aerated sand and grit removal channel and include the internal loadings at the plant.

	Turbidity	TSS	COD-tot	COD-sol	TP
	(NTU)	(mg/l)	(mg O_2/l)	(mg O_2/l)	(mg/l)
Average	136	285	605	247	6,8
Min	40	73	196	102	4,3
Max	400	1107	1110	323	9,0
n=	84	80	17	8	10

3.4. Results

3.4.1. No chemicals

Filter performance

The turbidity reduction obtained without chemical addition in the drum+discfilter system was 15% for average conditions (Figure 48). Maximum average turbidity-reductions obtained was 30% for more concentrated influent, and minimum removals of 12% for

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

more diluted influent. The drumfilter with 1mm media used as discfilter pre-treatment removed up to 15% of the entire system.

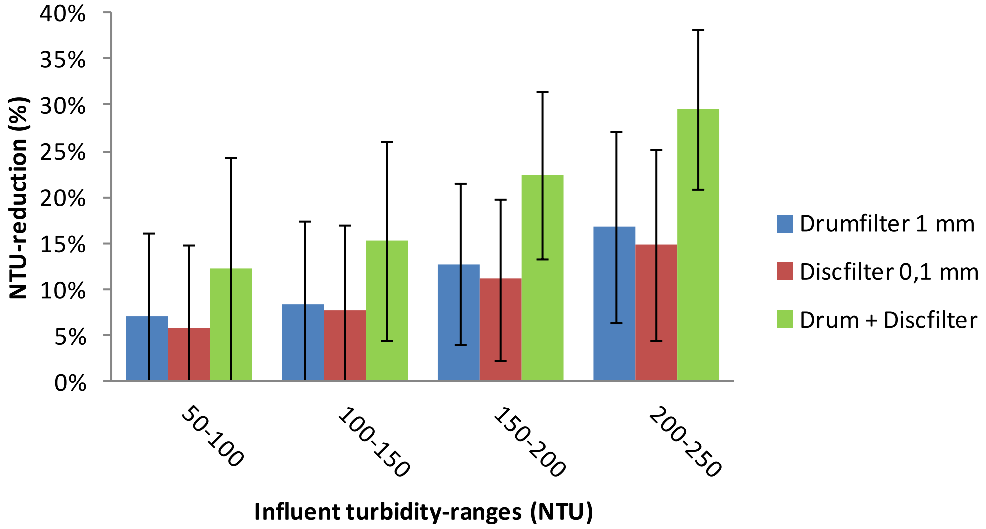

Figure 48: NTU-reduction without chemical addition at Sjölunda WWTP

The extrapolated TSS-reduction obtained without chemical addition was 40% for average (Figure 49). Maximum average TSS-reductions obtained was 50% for more concentrated influent, and minimum removals of about 35% for more diluted influent. The drumfilter with 1mm filter media removed 15-30% of the TSS.

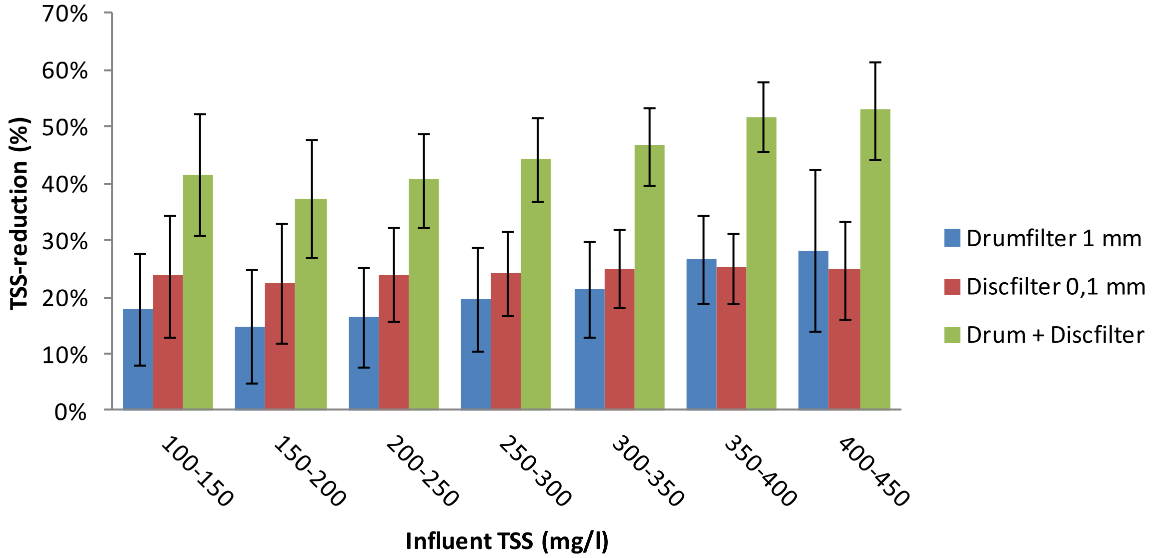

Figure 49: TSS-reduction without chemical addition at Sjölunda WWTP.

The estimated COD-reductions from turbidity readings obtained without chemical addition (Figure 50) was 30% for average conditions. Maximum average COD-reductions obtained was 35-45% for more concentrated influent, and minimum removals of about 20% for more diluted influent.

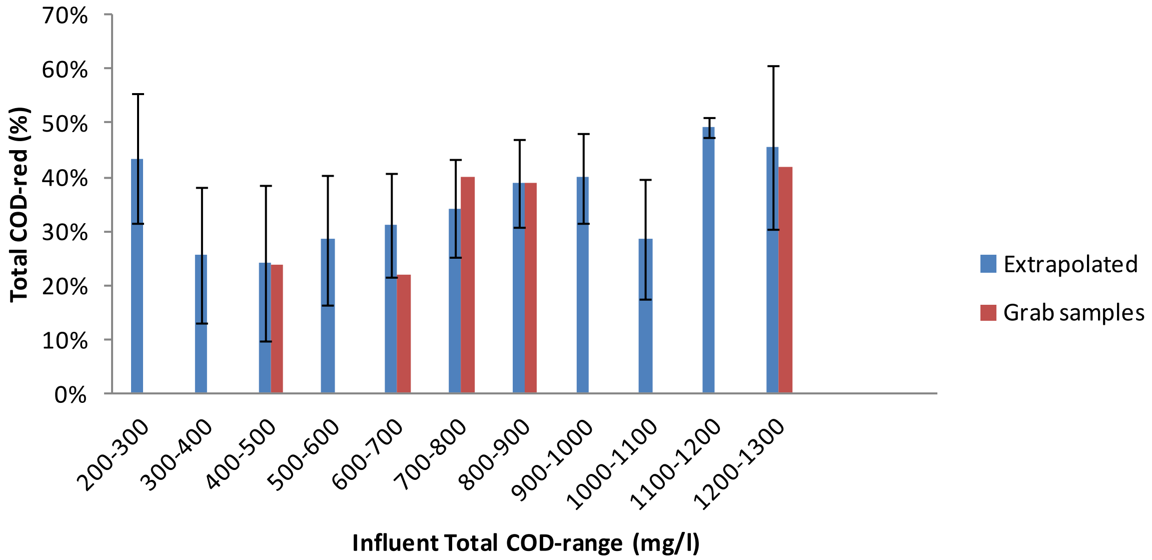

Figure 50: Total COD-reduction with standard deviation for influent total-COD ranges in the pilot plant without chemical addition.

Sludge production and characteristics

The sludge production by the Discfilter correlated with the solids loading of the filter, as shown in Figure 51. The sludge production by the Discfilter was less than 0.5% of the total influent flow when feeding the filter with 30m3/h (clean filter). Feeding the filter at 10m3/h for a long period resulted in long times without backwash, which lead to significant clogging. The clogging is leading to a higher sludge production due to the increased backwash frequency of the Discfilter.

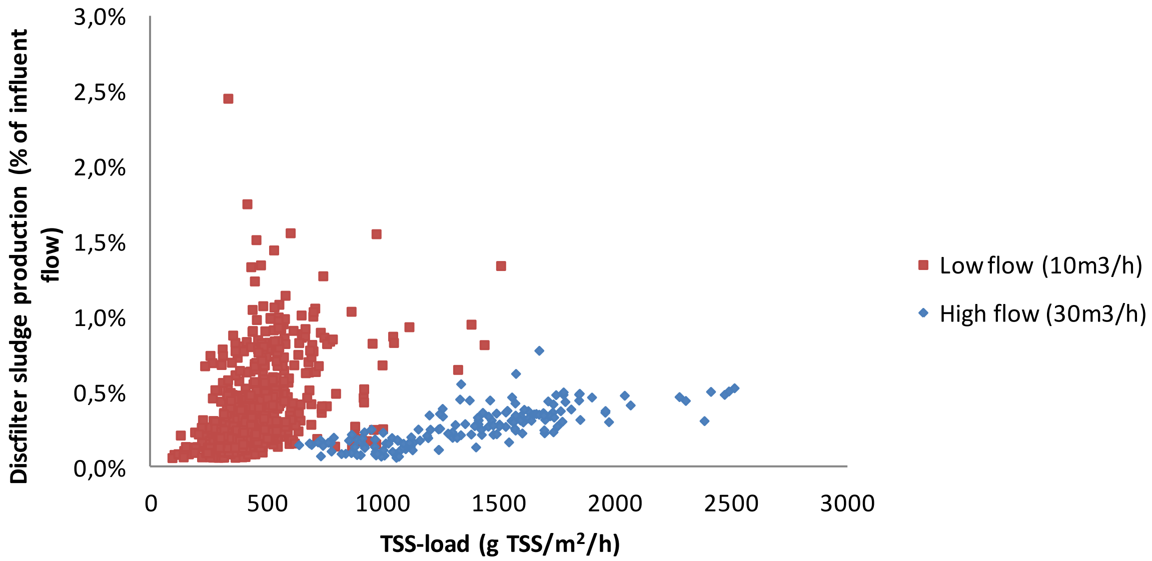

Figure 51: Discfilter sludge production in relation to actual TSS-load.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

The total solids content in the sludge from the drumfilter was in average 0,5% and from the discfilter 1,43% (Figure 52). The more diluted sludge from the drumfilter is due to tap water used for backwash, higher number of nozzles in relation to filter area and higher rotation speed lifting water up into the sludge trough, with the latter two being related to the specific filter model used. The sludge from the discfilter is in the expected range of 1-4% and indicates that it is able to handle the pre-screened primary wastewater without chemical addition.

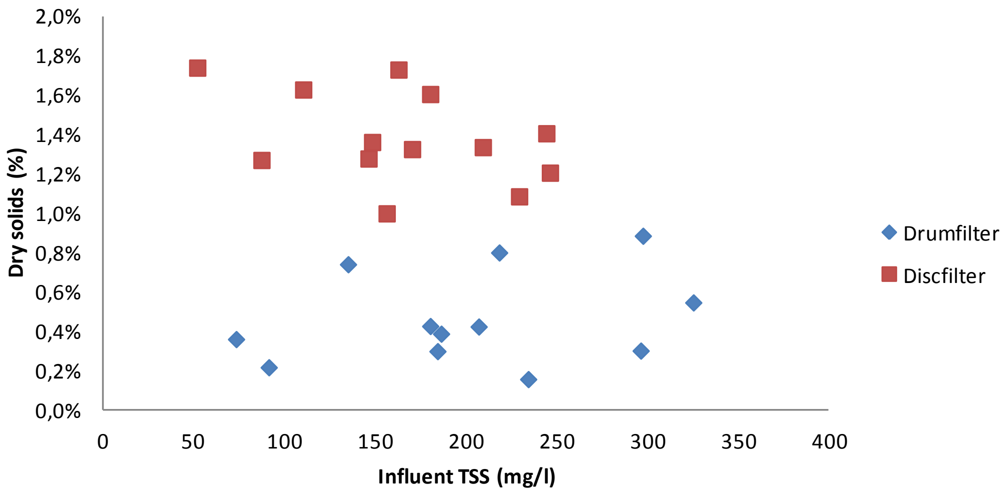

Figure 52: Total solids content in the sludge from the drum- and the Discfilter with corresponding influent TSS-concentration without chemical addition.

Energy consumption

The energy consumption of the Discfilter was mainly in the range 5-15Wh/m3 when running the filter at 10m3/h and 8 Bars backwash pressure (Figure 53).

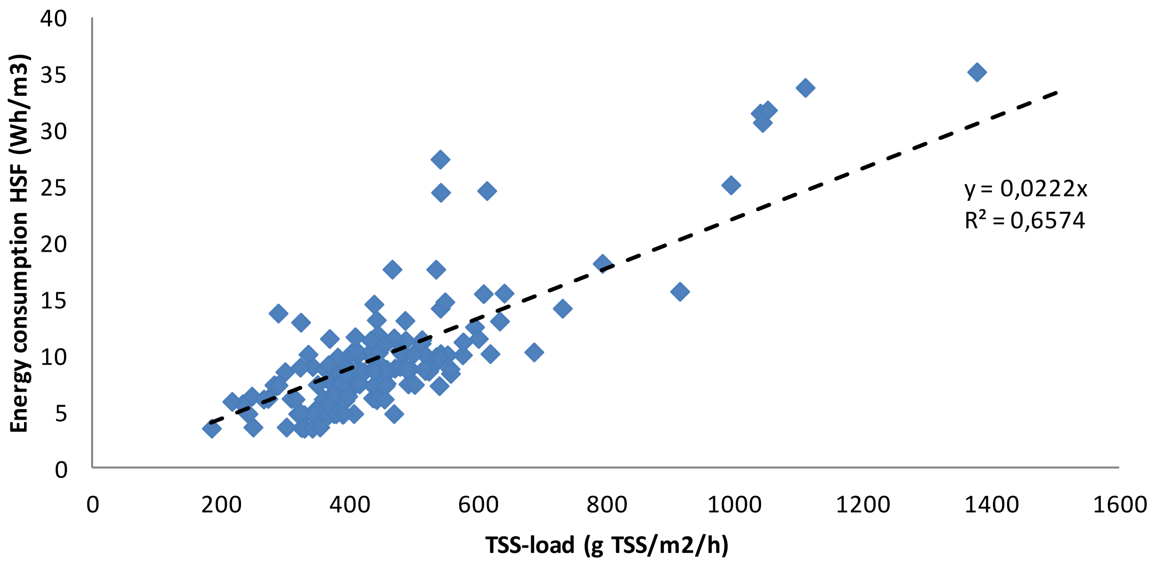

Figure 53: HSF energy consumption at 8 Bar at different loading conditions obtained at 10m^3/h.

A comparison of the average energy consumption suggests that the energy consumption decreases with 10-20% when running the backwash at 4 bar instead of standard 8 bar (Figure 54).

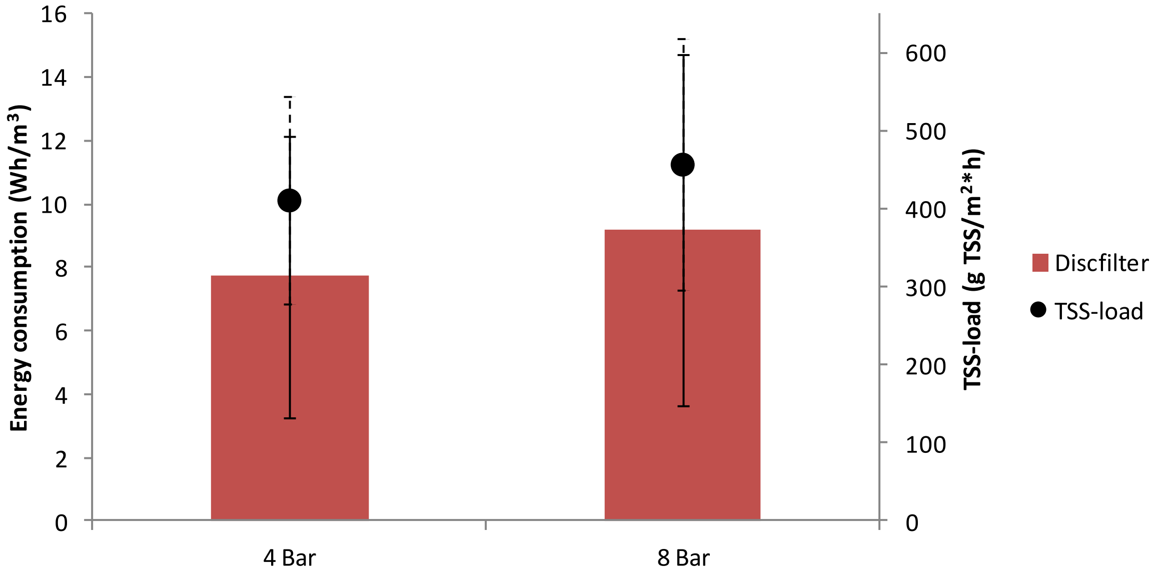

Figure 54: Energy consumption with standard deviation for the Discfilter with 4 & 8 Bars backwash pressure with corresponding TSS-load conditions.

Backwash frequencies

The solids loading and backwash frequencies for the discfilter without chemical addition are shown in Figure 55. The filter utilized only 40% of its maximum capacity for the peak loads observed.

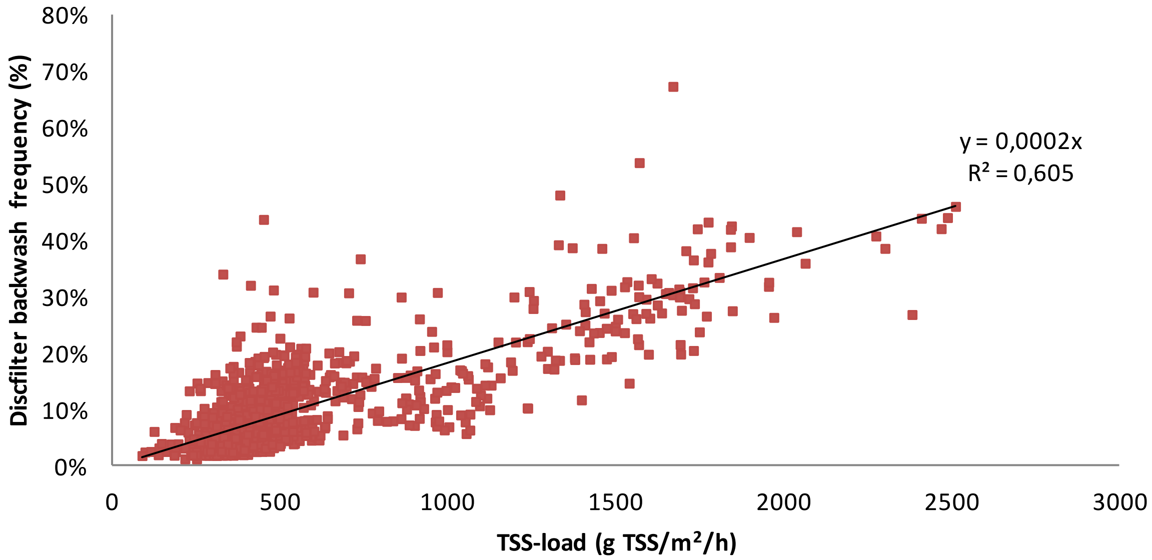

Figure 55: Solids loading onto the discfilter and corresponding backwash frequencies without chemical dosing

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

3.4.2. Flocculation with polymer

Mixing speed and impact on flocculation process

Mixing speed had to be high during the experiments due to the buildup of floating sludge in the flocculation mixing tank, therefore the impact of mixing was not evaluated. However, results from Westewitz does not show any impact on the performance correlated to the mixing speed for the tested range. At Sjölunda, mixing speed was within the range tested at Westewitz and as the hydraulics was similar in both sites.

Dosing strategies

Polymer addition was performed either with flow proportional dosing (Figure 56) or via feedback control and a fixed turbidity reduction rate (Figure 57). Experiments with flow-proportional dosing (2-4 ppm for 50-200 NTU influents) show a high variability of the turbidity reduction (5-90%). Lower turbidities were generally achieved with a higher polymer dose.

A fixed NTU-reduction of 55% was obtainable in average with the control loop with polymer dosing only. However, using the same control loop to obtain 80% NTU-reduction with polymer dosing failed. That test indicated that a maximum 70% NTU-reduction is obtainable with polymer dosing alone. To be able to reach better reductions, coagulant addition was necessary.

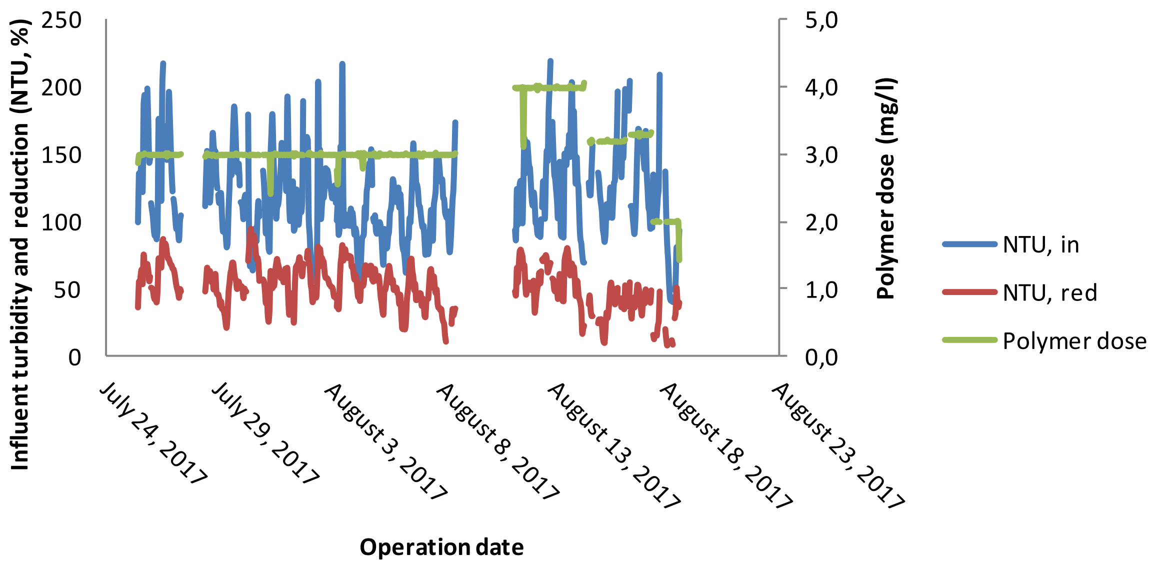

Figure 56: Results from test with flow proportional polymer dosing.

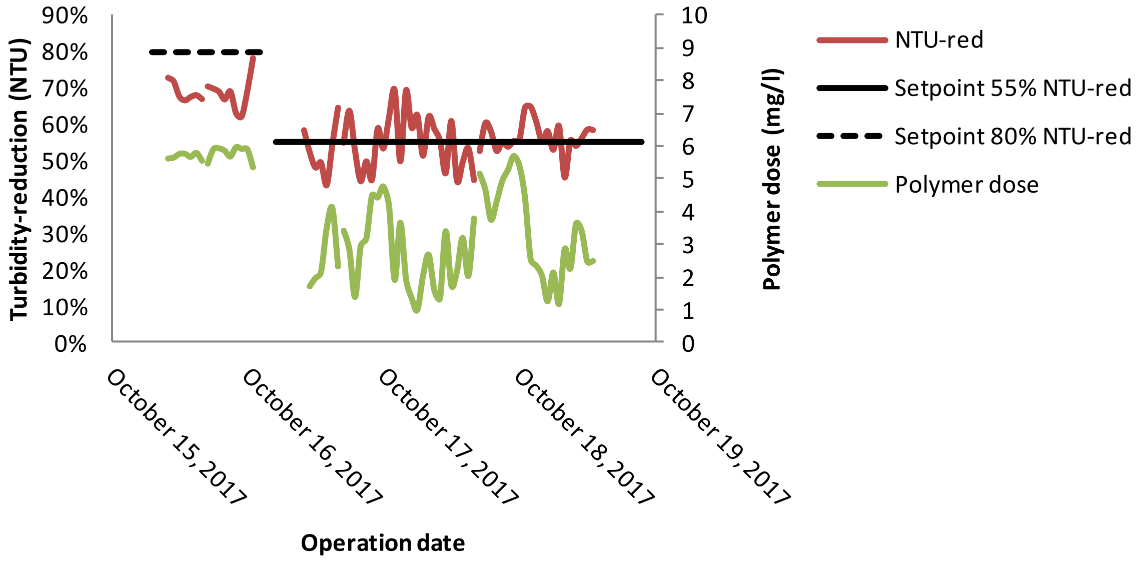

Figure 57: Results from test with fixed turbidity reduction controlled dosing.

Filter performance

The turbidity reduction obtained with flocculation applied during the test period in Figure 58 ranged between 40-60% depending on the polymer dose and influent concentration. The obtained reduction is significantly lower compared to pilot results with drumfilters, where up to 95% TSS-removals have been obtained with polymer dosing alone (Väänänen et al., 2016). One of the main reasons was accumulation of chemical sludge inside the Discfilter drum, especially after influent turbidity-peaks. This meant that the water that actually was filtrated (in the discfilter drum) had a significantly higher turbidity than measured in the pumping pit or the flocculation tank, leading to low removals.

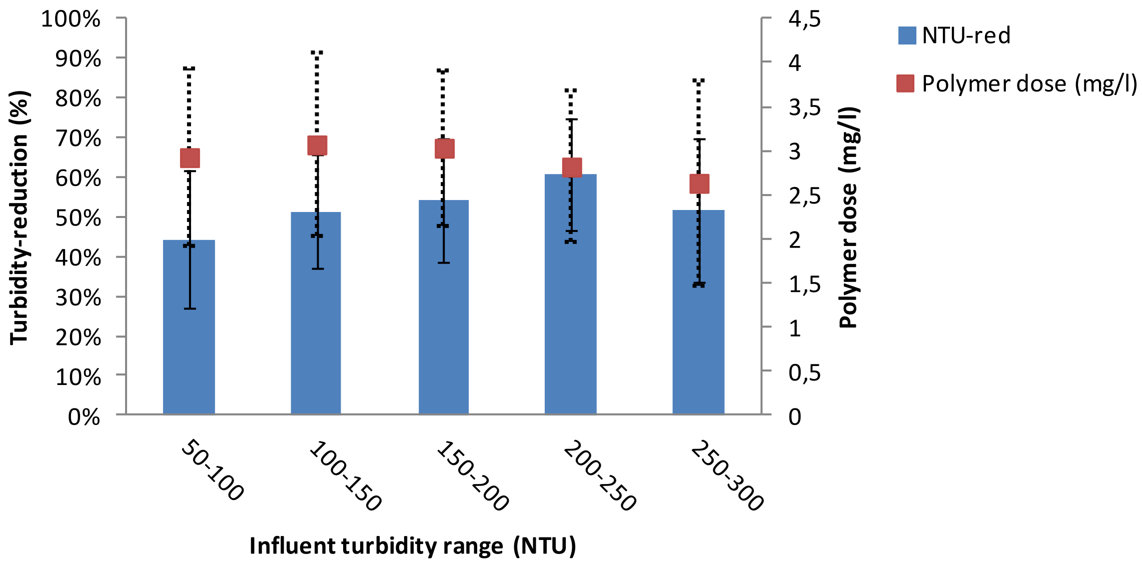

Figure 58: Turbidity-reduction with polymer addition.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

The extrapolated TSS-reduction obtained with flocculation during the test period in Figure 59 suggested reductions in the range 40-65% depending on polymer dose and influent concentration, which is also lower than expected as explained above.

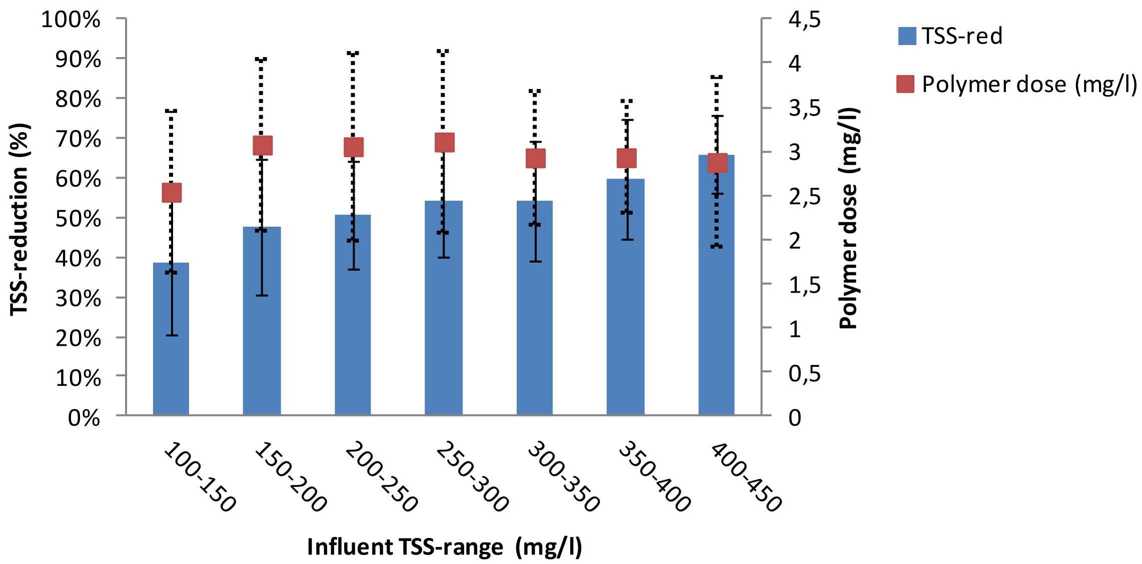

Figure 59: TSS-reduction with polymer addition.

Extrapolated total-COD removal for a polymer dosing range of 2-4 mg/l was in the range 10-55% (Figure 60). The soluble COD in the raw wastewater was in the range 250±100 mg/l which is not removed by polymer dosing only. Thus for more diluted wastewater samples the removal was expected to be lower.

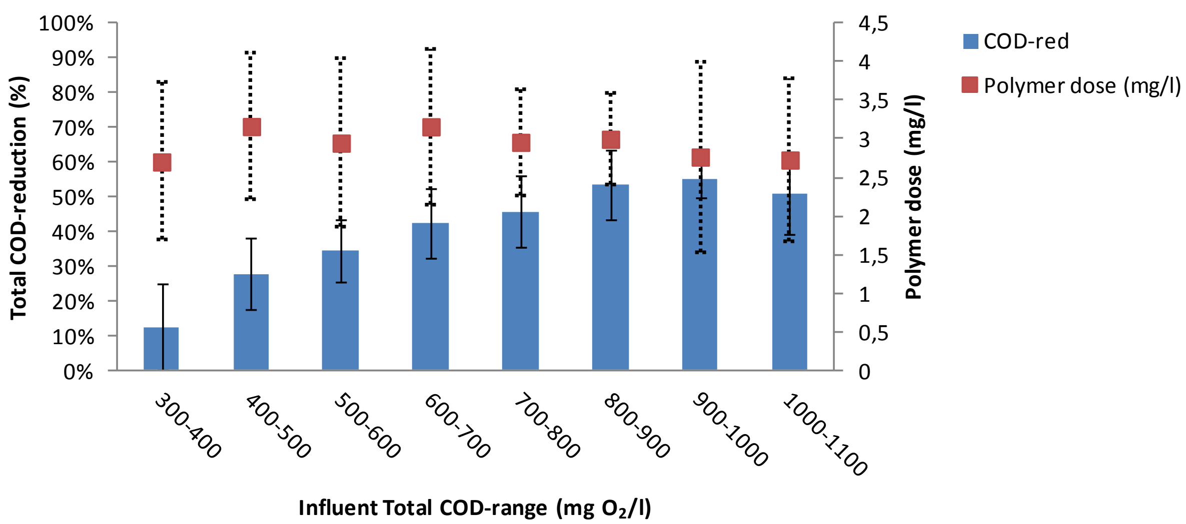

Figure 60: Total COD-reduction with polymer addition.

Sludge production

The sludge production from the Discfilter in Figure 61 suggests that up to 4-5% of the influent flow will end up as sludge. The expected sludge production is in the range 1-3% of the influent flow, but due to the solids accumulation of solids in the Discfilter drum, the filter capacity was low and thus the backwash more frequent also at low influent flows.

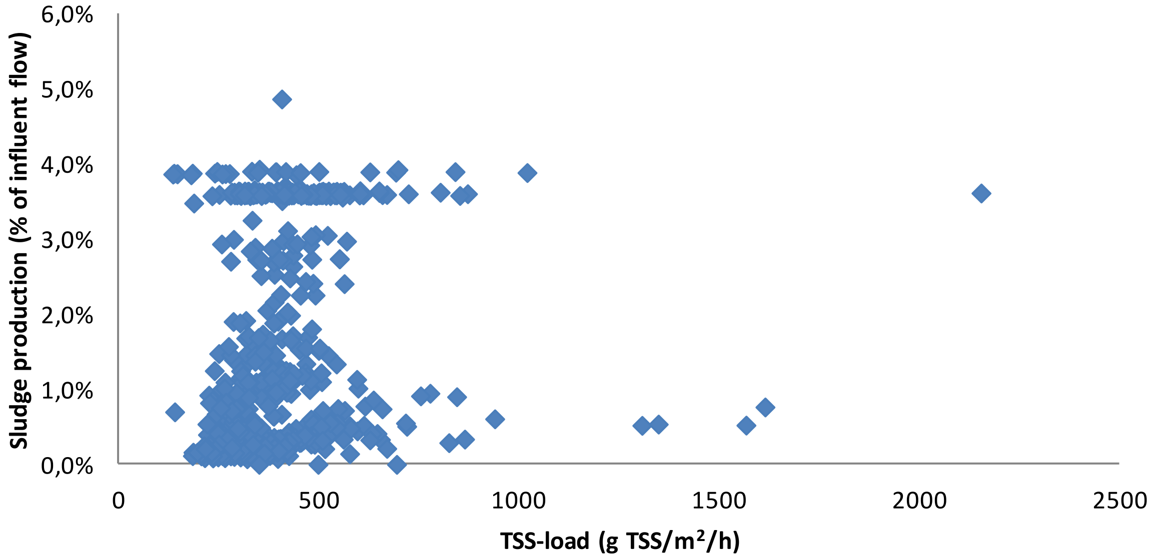

Figure 61: Sludge production as % of influent flow for actual TSS-loads with flocculation applied.

3.4.3. Coagulation and flocculation

Study of feedback control loop for chemical dosing

Feedback control of the polymer and coagulant dose was tested extensively at Sjölunda. The polymer and coagulant dose were controlled with the effluent turbidity via a feedback loop using a PI controller and an effluent turbidity setpoint. In this case 10 and 30 NTU were used as set points. As the objective was to obtain a preset effluent turbidity, the controller adjusted the chemical doses accordingly to keep the effluent quality at the set turbidity. Depending on the characteristics of the influent water, the polymer dose required to vary between 0-6 mg/L to attain the performance target (Figure 62). The polymer dose was limited to a maximum of 6 mg/l. To reach the 10 and 30 NTU in the effluent, coagulant addition was necessary.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

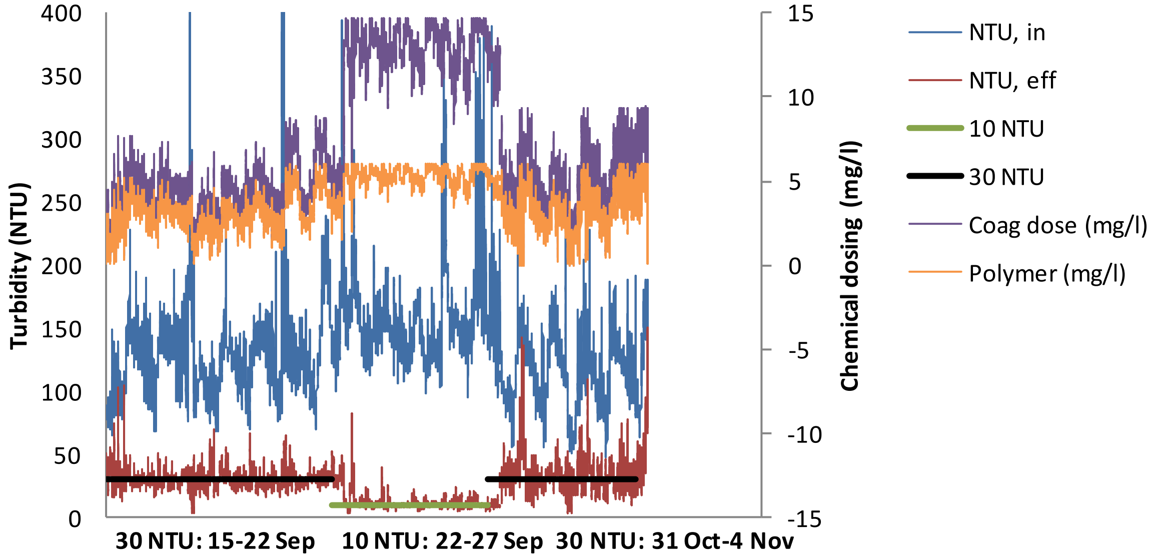

Figure 62: One minute averages for operation with two different settings, 10 NTU and 30 NTU setpoints.

Both effluent turbidity setpoints, 10 NTU and 30 NTU, were obtained in average (Figure 63). Thus by using feedback control of the chemical dose, the effluent turbidity was controllable. The average chemical consumption for 10 NTU was 5.3 mg polymer/l and 12.9 mg AL3+/l (Figure 63). Corresponding effluent concentrations for 10 NTU were 19 mg TSS/l and for total COD 198 mg/l (Figure 64 & Figure 65).

For the experiments at 30 NTU the chemical consumption was significantly lower. In this case a polymer dose of 3.4 mg/l and a coagulant dose of 5.1 mg Al3+/l were required (Figure 63). In this case the corresponding effluent TSS and total COD was 55 mg TSS/l and 251 mg COD/l respectively. Therefore there is potential for savings in chemical costs if the chemical dosing is controlled to obtain a desired effluent quality.

In average, up to 93% turbidity/TSS removals and 65% COD removals could be obtained consistently in spite of the issues with chemical sludge accumulation in the discfilter drum, which mainly affected the sludge generation and the filter capacity. Such removals are expected to be higher, as the pollutant concentration inside the discfilter drum is expected to be a lot higher than measured in the influent pumping pit.

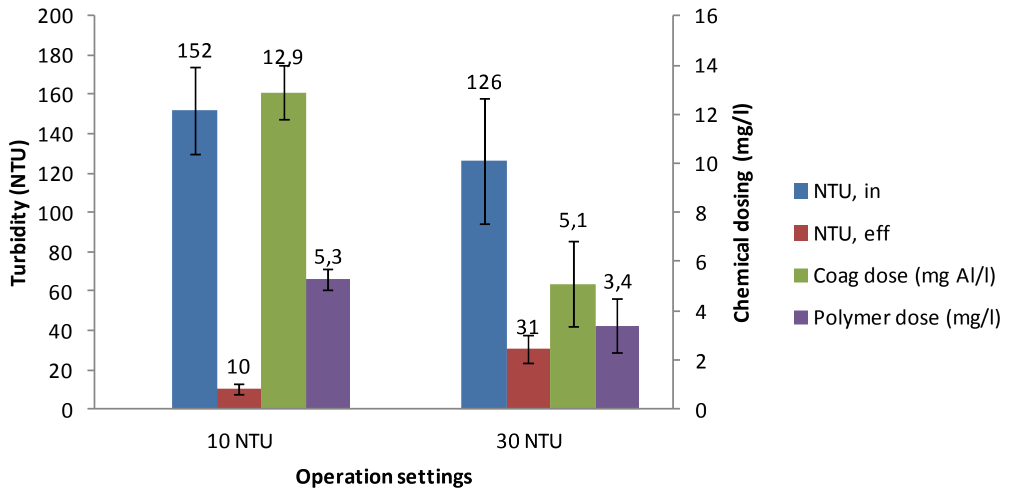

Figure 63: Influent and effluent turbidity with chemical doses for two different operation settings

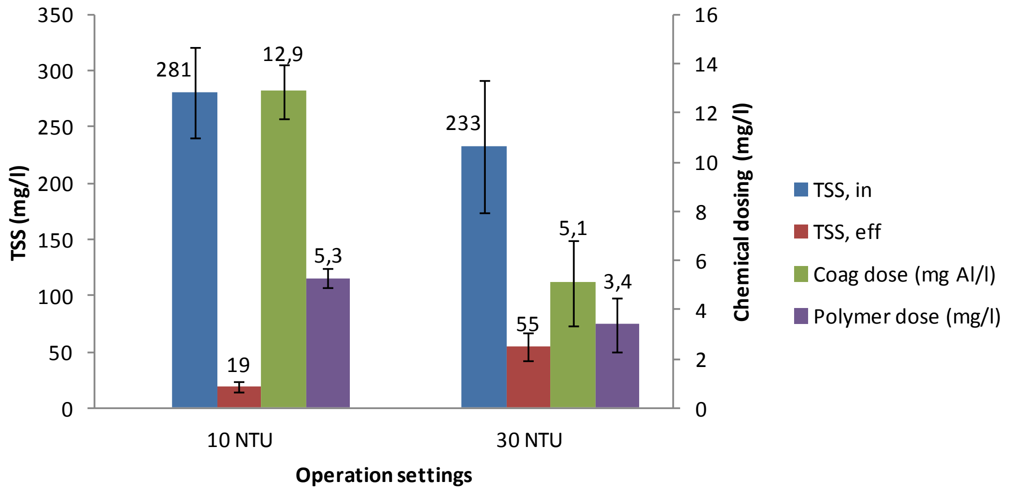

Figure 64: Influent and effluent TSS with chemical doses for two different operation settings

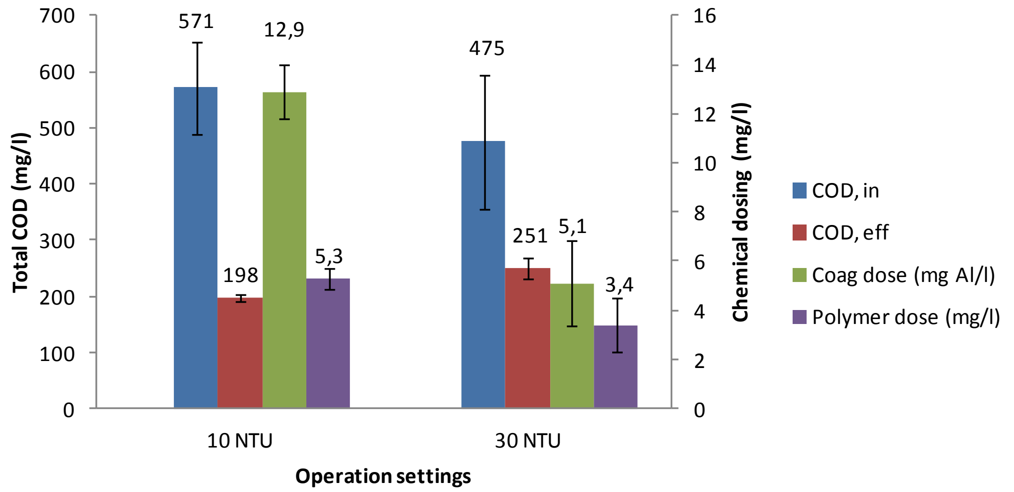

Figure 65: Influent and effluent total COD with chemical doses for two different operation settings

The total Phosphorus-removal from grab samples was in the range 50-95% depending on coagulant dose (Figure 66). High phosphorus-removals are only achievable by adding coagulant, in this case as Aluminium, as the major part of the influent phosphorus is soluble. The coagulant efficiently binds to the phosphates and converts them to particulate phosphorus, which can be removed by filtration. A higher dose generates higher removals.

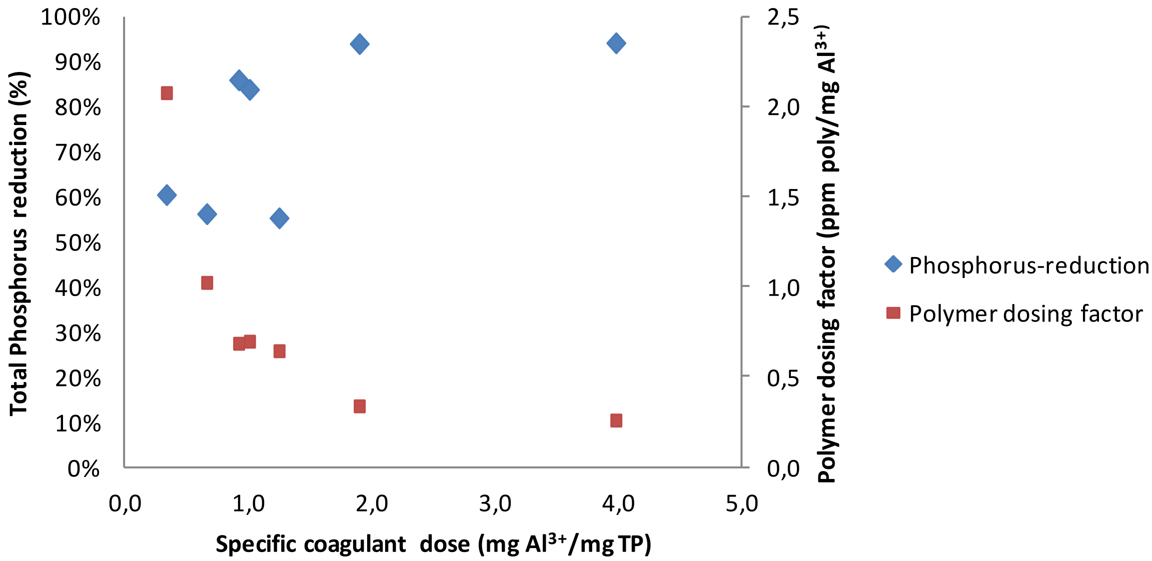

Figure 66: Phosphorus-reduction in relation to specific coagulant and polymer doses.

Energy demand

The operation with both coagulation and flocculation applied suggests total specific energy consumption by the plant to be in the range of 110-135 Wh/m3 (Figure 67). More than half of the energy was consumed by the mixers and the chemical equipment and the rest mainly by the Discfilter. The main reason to the high energy consumption by the Discfilter was that chemical sludge was accumulating inside the drum of the Discfilter, leading to very low hydraulic capacity. The energy consumption by the mixers would have been the same even if the flow had been 5 times higher as the coagulation and flocculation system was designed for. This means that the specific energy consumption is expected to be in the range of 7-10Wh/m3 for this particular installation at design flow.

The energy demand by the dosing pumps and the polymer station increases with increased flow and thus higher chemical flows, so the effect is not as big as for the mixers. It has to be noted that the energy demand by the pre-screening drumfilter presented in the figure does not include the energy needed for the backwash since internal technical water supply at the plant was used without pressure increase.

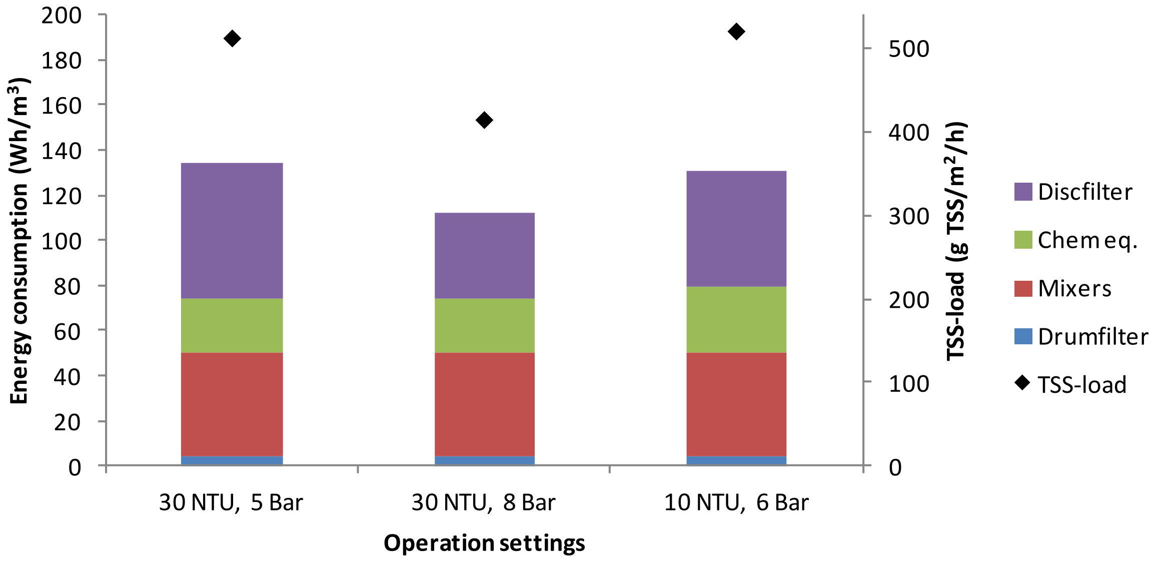

Figure 67: Energy demand with coagulation & flocculation applied.

Sludge production and characteristics

The sludge production was most of the time 0.5-3% of the influent flow, with maximum sludge flows of 5%. The large variation of sludge production at similar loading condition is mainly due to the low capacity obtained with the Discfilter due to chemical sludge accumulating in the Discfilter drum.

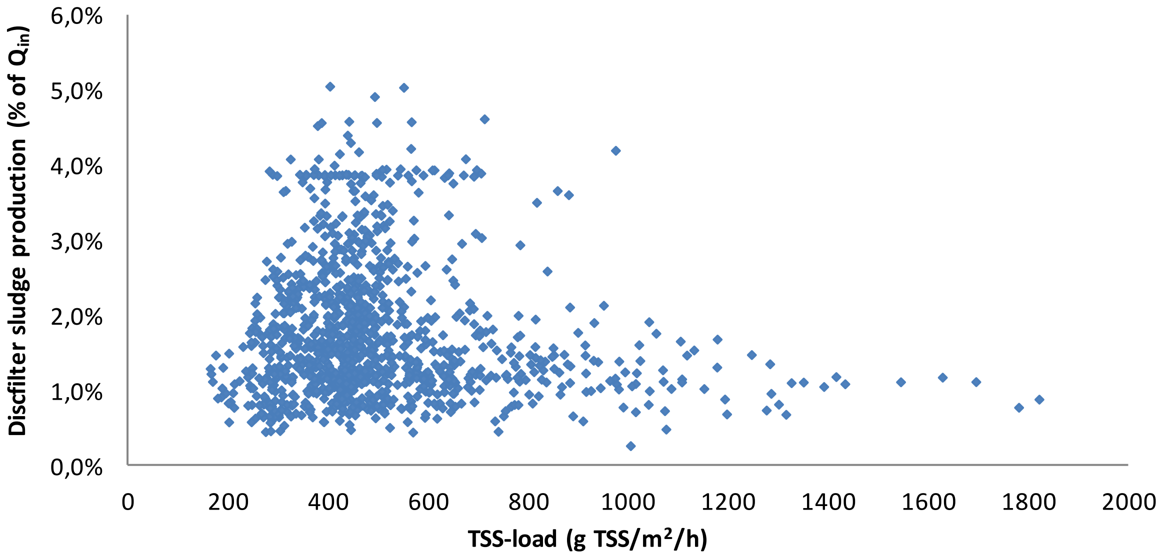

Figure 68: Discfilter sludge production in relation to solids loading when operated with coagulation & flocculation.

The total dry solids in the sludge produced by the Discfilter were in the range of 0.7-1.6% (Figure 69). This was similar or slightly lower compared to when running the filter without chemicals (Figure 52). Since the TSS-removals are higher with chemicals dosed, the

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

expected sludge dryness should be higher than operating without chemicals. However, the low capacity is leading to high backwash frequency that dilutes the sludge and thus, the sludge dryness gets lower than expected.

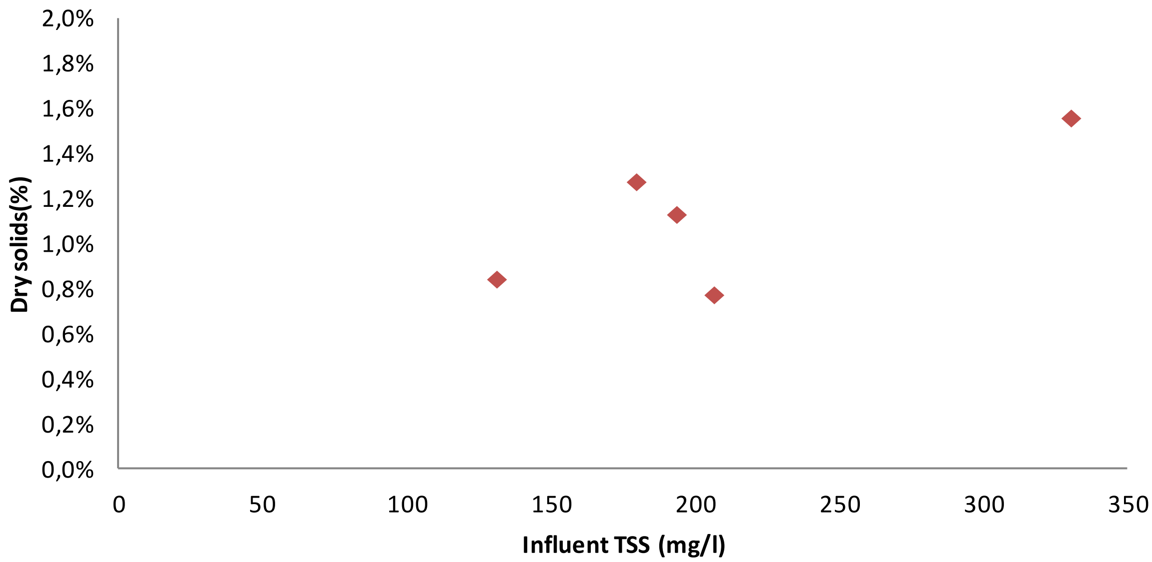

Figure 69: Dry solids in sludge from Discfilter in relation to influent TSS when operated with coagulation & flocculation.

3.5. Maintenance needs

3.5.1. Discfilter

After 15 weeks of operation without chemical pre-treatment, the capacity of the filter panels was down to 70% of original capacity (Figure 70). After automatic high pressure cleaning at 80 bar pressure, the capacity recovered to 85% of original capacity. After a one stage chemical cleaning with NaClO (2%), the capacity was back to 92% of original capacity (for full recovery a two stage chemical cleaning with HCl and NaClO would be required). These results suggest that regular high pressure cleanings of 1-2 times per month can decrease the need for chemical cleaning and still keep 80-90% of the capacity for several months when using 100µm filter media.

If no regular cleaning is performed during a longer period (32 weeks, as tested here), the remaining capacity may be as low as 20% of the original capacity (Figure 70). A high pressure cleaning at this stage was only able to recover the capacity to 40%, however a one-stage chemical cleaning with NaClO recovered the capacity back to 85-90% of the original capacity. Full capacity is expected to be recovered with successive cleanings.

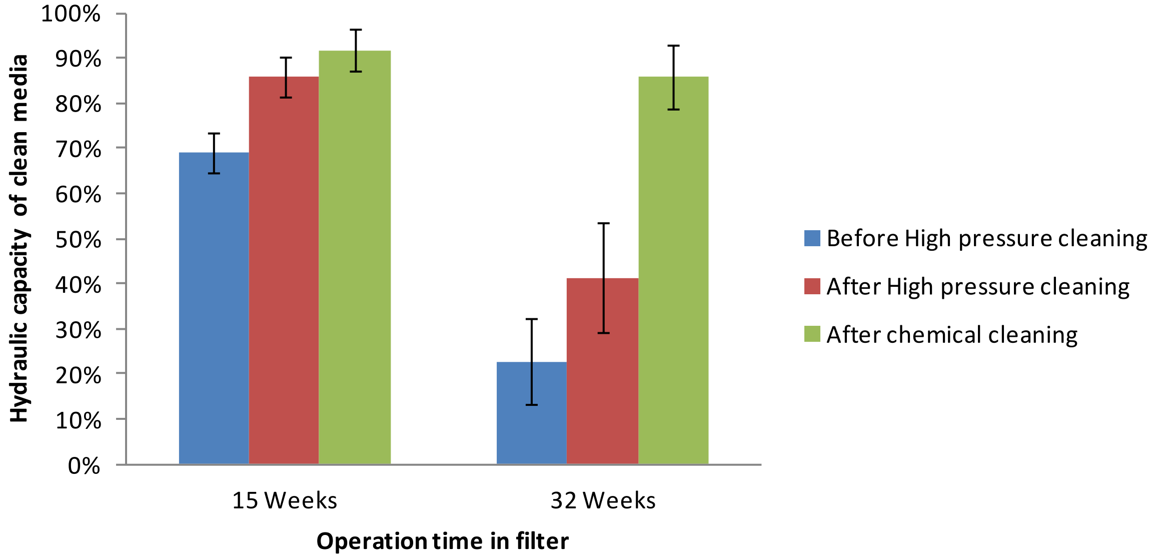

Figure 70: Effect on filter capacity recovery for high pressure cleaning and chemical cleaning with NaClO.

During operation at high carbon removal (target 10 NTU in effluent) with coagulation & flocculation it was observed that the maximum loading capacity decreased to 50% within one week (Figure 71). Such decrease is due to the high chemical doses applied, which clogged the filter panels. This additional maintenance requirement has to be taken into consideration when operating at this high removal. Applying these high chemical doses will require more frequent chemical cleaning to maintain the filtration capacity.

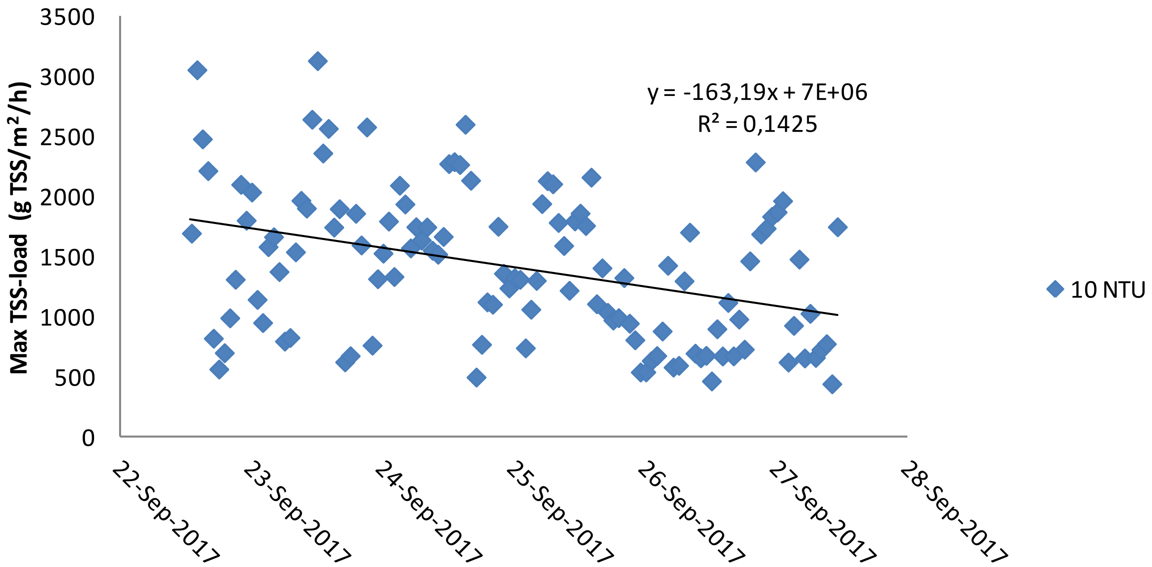

Figure 71: Capacity loss in the disc filter in a period of one week operating it with coagulation & flocculation for high carbon removal efficiency.

The capacity loss occurring as a result of clogging of the filter media is not permanent and it can be recovered by applying chemical cleaning. The effect of one such chemical cleaning event after 32 weeks of operation can be seen in Figure 72. The high pressure cleaning at 80 bar was not as effective remediating this clogging and only 50% of the original capacity could be recovered.

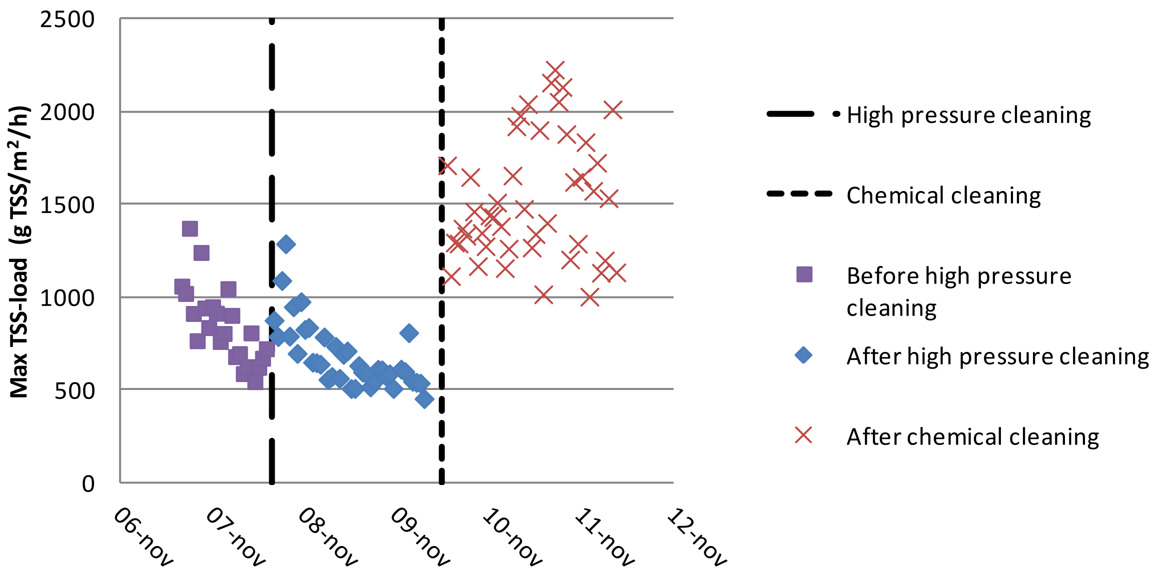

Figure 72: Solids load capacity gain with high pressure cleaning (HPC) and chemical cleaning with NaClO during a period with coagulation and flocculation to reach 30 NTU in the effluent.

3.5.2. BW-pump

No maintenance of the backwash pump was required during the test period, even though it was fed with filtrate.

3.5.3. Nozzles

Self-cleaning nozzles fed with filtrate were used during the entire test with very good results. No clogging was observed and no maintenance was required throughout the test. The only limitation that was noted was that the spraying angle was affected when applying backwash pressures below 4 Bars.

3.5.4. Automated high-pressure cleaning

No maintenance issues were experienced with the high pressure system during the test period. However, at the end of the test it was noted that the spraying arm was returning to a position which was higher than the original setting. The reason to this is unknown, and was first discovered after the filter was taken out of operation.

3.5.5. Automated chemical cleaning

The automated chemical cleaning equipment worked fine, but was only used once during the operation period as 100µm filter media takes a long time to clog. The only issue experienced with the chemical cleaning was clogging of the chemical spraying nozzles by biofilm as for the case in Westewitz.

3.5.6. **Online sensors**

No issues have been experienced during the operation period. The included wiper keeps the glass window where the sensor is placed clean without any manual maintenance for at least 2-3 months. Except from the maintenance needs listed in the operation manual for the instrument it is advised to clean the sensor window with glass detergent once every 1-2 months to secure proper operation, especially when using turbidity controlled chemical dosing.

3.5.7. **Mixers and coagulation/ flocculation tanks**

No issues or maintenance needs regarding the mixers have been identified during the operation period with the 1 mm pre-screening drumfilter. The only issue occurring was a thick sludge layer forming on the surface of the flocculation tank during periods with high polymer doses. To prevent this layer from forming, a surface scraper was mounted onto the mixer. With this change in combination with high mixing speed, the sludge formation could be prevented. However, if the mixing speed was low, there was still a surface sludge layer forming in the corners of the flocculation tank.

3.5.8. **Polymer station and dosing pumps**

No issues have been experienced with the dosing pumps or the polymer station. Same maintenance needs applies as described in the Westewitz section.

3.6. Sludge thickening

As the pilot tests described in this report has shown, the total solids in the sludge out of the microscreens were mainly in the range of 1-2%, which may be an issue if sludge has to be transported or digested in the plant. There are several technologies available in the market to increase the solids content in the sludge depending on what dry solids content is requested. In the case study at Sjölunda, the sludge from the filters was thickened with gravity in a sludge tank before it was transferred and mixed with other sludge flows at the plant, before it was processed in the digesters. In the case study in Sjölunda it was also decided to do a screw press trial to get a better understanding on what dry solids content that can be achieved, for example for cases where combustion of the sludge would be an option.

3.6.1. **Test setup**

The test setup in Sjölunda included a small flocculation vessel and a screw press designed for a solids loading of 70 kg TS/h (Figure 73). There are two ways to control the resulting dryness of the sludge, one is the pressure in the unit and the other is the polymer dose. Different combinations of these parameters were tested in order to obtain varying sludge dryness and reject water quality.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Figure 73: Screw press setup in trailer (left), closed flocculation chamber (middle) and thickened sludge (right).

3.6.2. Results

The screw press test suggests that depending on the cone setting (1,5-6) and the feed pressure (0,02-0,03 bar) in the screw-press and the applied polymer dose (3-12g polymer/kg TS), a dry solids content in the range of 25-45% can be obtained (Figure 74). The test indicated that higher dry solids content could be obtained for primary sludge from operation without chemical addition compared to operation with coagulation and flocculation prior to the Discfilter. The quality of the reject water from the screw press was in the range 13-63 mg TSS/L, with the lower values obtained with the highest polymer doses.

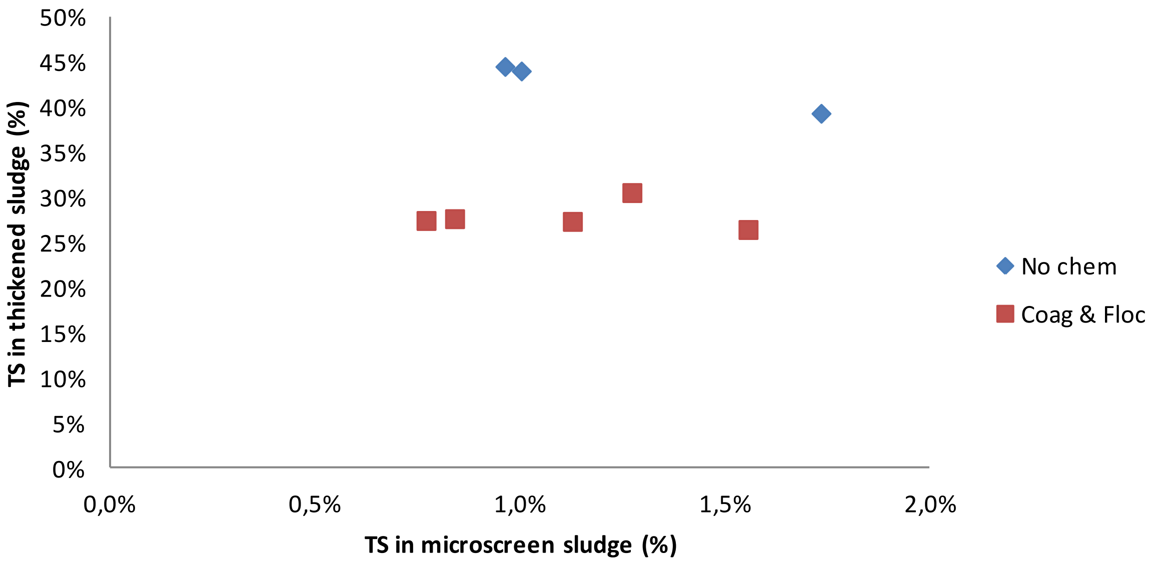

Figure 74: Total solids dryness in the thickened sludge after the screw press.

4. Recommended design for primary treatment with microscreens

4.1. Filter design without chemical addition

The summary of the filter performances in Westewitz (40µm, Drumfilter) and Sjölunda (100µm, Discfilter) is shown in Table 6. The estimated maximum design capacity for both pilots was similar, even though a higher capacity is expected for the 100µm filter media. As explained previously, the influent TSS were measured in the influent pumping pits, far from the drum of both the disc and the drumfilter. However, it is known that solids accumulate inside the drum of both filters. The data indicates that the drumfilter was more efficient in getting the solids out of the drum compared to the Discfilter. This is expected given that the support for the filter media in the drum filter is designed to dig out solids, which is not the case for the discfilter panels. As the solids loadings were obtained from backwash frequencies <20%, the extrapolation of the max solids loadings may not be fully representative of a full scale installation. There is unfortunately no data with higher backwash frequencies for clean filter media available for this project due to influent flow limitations.

Removals were overall similar for the two setups (Table 6), suggesting that 100µm is a better choice in order to minimize the size of the installation due to higher hydraulic capacity. The only main difference in removals was found for turbidity, which was significantly higher in Westewitz. However, the influent turbidity was 70% higher in Westewitz during average conditions compared to Sjölunda even though the TSS was almost identical. This suggests that it is rather the composition of the wastewater that is causing the large difference in NTU-removal and not the filter opening.

Table 6: Extrapolated maximum load (clean filter) and removals without chemical addition at the average conditions in Powerstep

	Max-load (g TSS/m^2*h)	NTU-red (%)	TSS-red (%)	COD-red (%)	TP-red (%)
Sjölunda (100µm, Discfilter)	5000	15±11	44±7	28±10	<10
Westewitz (40µm, Drumfilter)	5000	36±13	51±10	23±15	11±10

The recommended microscreen setup to use for primary treatment after coarse screening and grit removal without chemical pre-treatment is a drumfilter with 100µm filter opening.

4.2. Filter design with chemical addition

4.2.1. Chemical screening

Jar tests followed by filtration with different pore sizes were performed in lab scale prior to the pilot trials to find out which chemicals were the most suitable to use on the different sites (Deliverable 1.1). The results from these tests suggested that a cationic polymer with very high molecular weight was the most suitable, especially without the coagulation stage. The results show that pre-lab tests are an excellent tool to predict the performance of a microscreen in primary treatment applications.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

A comparison of the lab test results and the pilot results from Sjölunda suggests that the chemical doses required in the Discfilter pilot to reach the same removals as in the lab scale was much higher. For total COD it was not even possible to reach the removals obtained in the lab scale even at high coagulant doses. The reason to this is probably due to a combination of chemical sludge accumulating inside the filter drum due to the lack of the lifting aid found in the drumfilter, and also by flocs breaking during the drum rotation, making them smaller than the 100 µm filter opening.

Table 7: Comparison between results from lab tests and pilot test at Sjölunda for operation with coagulation and flocculation.

	Al-dose (mg Al^{3+}/g TSS)	Polymer dose (ppm/g TSS)	TSS-red (%)	COD-reduction (%)	Max TP-reduction (%)
Jartest, lab	26	20	98%	87%	94%
Pilot (10 NTU)	46	19	93%	65%	94%
Pilot (30 NTU)	22	15	76%	47%	60%

The TSS-removals obtained in the pilot in Westewitz for the same specific chemical doses were in the same range as obtained during the lab trials and suggests that the chemical enhancement and the following screening of the flocs was working well (Table 8). Using a drumfilter for this application is advantageous in the way that the flocs going into the filter can sediment down onto the filter media during the static period in between the backwashes. Then the support frame of the filter panel will lift the settled flocs into the sludge trough during backwash without damaging the flocs. The COD-reduction was lower in average during the pilot trials with coagulation and flocculation compared to the lab trials, however individual grab sample results showed that COD-reductions above 70% was obtained several times, in spite of the difficulty in obtaining a stable coagulant concentration in the coagulation tank.

Table 8: Comparison between results from lab tests and pilot test at Westewitz for operation with chemical dosing.

	Al-dose (mg Al^{3+}/g TSS)	Polymer dose (ppm/g TSS)	TSS-reduction (%)	COD-reduction (%)
Jartest (Floc)	0	5	62%	
	0	12	80%	
	0	21	81%	
Jartest (Coag & Floc)	11	11	91%	76%
Pilot (Floc)	0	5	65%	
	0	12	75%	
	0	21	78%	
Pilot (Coag & Floc)	12	11	86%	60%

4.2.2. Design of the coagulation and flocculation stages

The rectangular coagulation tanks used in both the projects were designed for a minimum retention time of 1-2 minutes. Retention times of 1-2 minutes were tested in Sjölunda without any identifiable decrease in floc strength compared to longer retention times. Mixing intensities in the range 70-150 rpm was in general used in the coagulation stage without any noticeable change in floc strength. The dosing point for the coagulant was an injection valve placed in the influent pipe to the coagulation tank using only the turbulence in the flowing water.

For the flocculation process the design retention time in the rectangular tank was 3-4 minutes and polymer was dosed into a funnel shaped pipe with high turbulence, but with no other mixing. No problems with the retention time or the injection point were noted during the piloting. However, during events with high polymer doses applied, a sludge layer was formed at the surface of the flocculation tank (Figure 75). In order to avoid this, a surface scraper was mounted on the flocculation mixer, which in combination with high mixing speeds above 25 rpm seemed to counter the sludge layer formation. Installing baffles or changing the tank geometry may be other options to avoid sludge layer formation.

Figure 75: Different stages in the formation of sludge layer in the flocculation tank

Selecting the size of the dosing pumps could be challenging for primary applications as the influent quality could vary significantly and peak influent concentrations often occur in parallel with high flows due to heavy rain events. This means that the dosing pumps should be able to give the peak doses also during high flows and high TSS conditions.

The polymer station used in the experiments was designed to work with either polymer emulsion or, as used in the pilots, powder polymer. As for the dosing pumps, it is important that the polymer station is designed to be able to prepare polymer for the peak conditions. In addition to this, the polymer should not be left standing during longer periods at low dosing conditions. The polymer station used can prepare solutions >0,2%, which is expected to last longer also during warm weather compared to the 0,1% solution used in the project. Using thicker polymer solutions may require post dilution with water. The preparation water feed pressure should be above 3.5 Bar, if the feed pressure is lower, the mixing of the polymer powder does not work and blockages may occur.

The operation of the pilots tested in the project has been done with a PLC with a program specifically made for these installations. It was demonstrated that the chemical dosing can be optimized with the right type of sensors to meet specific effluent qualities, as explained. Another advantage is that it is possible to obtain a high

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

volume of operation data, from which operation issues can be identified and corrected fast.

4.2.3. Filter design

The extrapolated max solids loadings for operation in Westewitz with flocculation prior to the drumfilter (Table 9) show that the filter could double its maximum loading rates when a polymer is dosed upstream. Such data was obtained from backwash frequencies <10% and may not be representative of a full scale installation. Higher backwash frequencies give a better estimation, but were not possible to achieve with the clean filter media due to influent flow limitations for this type of operation.

For the operation with coagulation and flocculation, the max solids loading was significantly lower than operating only with polymer dosing or without chemicals (Table 6 and Table 9). The main reason to this was that the test performed was focused on targeting a specific turbidity-reduction rather than maximizing the capacity. When operating the process this way, the chemical doses will vary significantly leading to periods with both underdosing and overdosing of chemicals. These situations are expected to decrease the capacity of the filter and show that it is important to take this into account when designing a full scale plant, especially when there is a need for either phosphorus-removal or high carbon extraction requiring the coagulant stage.

The Discfilter at Sjölunda was not performing very well in terms of hydraulic capacity when adding chemicals due to build up of chemical sludge inside the drum, especially during periods with highly concentrated influent. With the drumfilter being more efficient in handling high solids peaks, chemical sludge and also being able to handle wastewater with coarser screens as pre-treatment, the recommendations is to use drumfilter in chemically enhanced primary treatment applications.

Table 9: Extrapolated max solids loading and average removals (*,after chemical cleaning)

	Operation condi-tion	Max TSS Load (g/m2*h)	Average dose (mg/L)	NTU-red (%)	TSS-red (%)	COD-red (%)	TP-red (%)
Westewitz (40µm, Drumfilter)	Flocculation	11100*	4 poly	67±15	73±12	47±9	26±12
	Coag & Floc	1700*	1.5 Al+3 poly	74±14	80±11	53±14	44±10
Sjölunda (100µm, Discfilter)	Flocculation	-	3 poly	51±14	54±14	42±10	-
	Coag & Floc, 10 NTU	-	13 Al+5 poly	93±2	93±2	65±5	-
	Coag & Floc, 30 NTU	-	5 Al+3 poly	75±8	75±8	44±14	-

The recommended design for use of microscreen after chemical pretreatment with either flocculation alone or coagulation and flocculation combined is to use a drumfilter with 100µm filter opening.

4.3. Accesory microscreen equipment

Given the experience gathered in the project, the following equipment is recommended to be installed in the microscreen:

- Automated chemical cleaning
  - Check of chemical nozzles, use of tap water to check spraying angles
  - Combination of HCl and NaClO needed, especially when dosing coagulant
  - Flush the chemical dosing system with tap water after use
  - HCl-concentration required (7-10%)
  - NaClO-concentration required (2-3%)
  - If severly clogged filter, several cycles of each chemical may be required
  - If automated high pressure cleaning is installed, it is advisable to combine it with the chemical cleaning if the filter is heavily clogged.
- High pressure cleaning
  - Doesn't require much time to run, if fully automated
  - If regularly used, it will increase the time in between chemical cleaning events
  - Works best with drumfilter as particles will not risk to end up on opposite filter panel
  - Requires technical water
- Self-cleaning nozzles
  - Worked well with filtrate when using 100µm filter media at backwash pressures above 4 bar
  - Requires mixed bypass solution
  - Clogging may occur if panel breaks
- Self-cleaning strainer
  - Works for filtrate when using 40µm filter media
  - Can clog due to residual aluminium if flocs breaks or during overdosing
  - Clogging can be removed manually if necessary by opening the strainer and flush it with high pressure cleaner
  - Will require a non pressurized pipe for the waste sludge after each self-cleaning event.
  - Will temporarily decrease the backwash pressure in the backwash line, important to think of this when applying dry running protections using the backwash pressure.
- Backwash pump
  - If filtrate is used, it is important to use pumps with larger openings in the pressure system where there is no risk of biofilm growing too thick, thus leading to clogging

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

- Nozzle in sludge trough
  - Especially for longer filters to avoid clogging of the sludge trough. This is especially important for installations with poor pre-treatment.

4.4. Maintenance requirements

Based on the experience gathered during the operation of the plants designed for this project, it is recommended to include the operations described in Table 10 and Table 11 in the maintenance schedule of a plant for primary filtration

Table 10: Maintenance requirements for the filter

Maintenance	µm	Frequency	Time required	Comments
High pressure cleaning	40	Weekly	<5 min	Installation dependent
	100	Weekly	<5 min	Installation dependent
Chemical cleaning	40	Monthly	1-2h	Installation dependent
	100	Every 2nd month	1-2h	Installation dependent
Level sensor cleaning (inlet)	N/A	Monthly	<5 min	Installation dependent
Nozzle check	N/A	Weekly	<5 min	Check for clogging
Filter panel check	N/A	Weekly	<10 min	Check for damages
Sludge trough check	N/A	Weekly	<5 min	Check for blockages
Check inside drum		Monthly	>10 min	Check for stuck rugs
Backwash pump		Yearly	>2h	Installation dependent
Self-cleaning strainer		Monthly	<15 min	Operation dependent

Table 11: Maintenance requirements for the chemical equipment and sensors

Equipment	Maintenance	Frequency	Time	Comments
Polymer station	Refilling/Calibrating	Every 2nd month	1h	Installation dependent
Polymer station	Cleaning	Every 3rd month	2h	Installation dependent
Dosing pumps	Calibration	Every 2nd month	<15 min	
Turbidity sensors	Cleaning	Every 2nd month	<15 min	
Mixers	Cleaning	Monthly	>10 min	Only if bad pre-screening
Coagulation tank	Cleaning	Every year	>1h	Installation dependent
Flocculation tank	Cleaning	Every year	>1h	Installation dependent

4.5. Mechanical pre-treatment requirements

When using microscreens for primary treatment the minimum requirement for pre-treatment prior to the microscreen is to have a coarse screening with maximum diameter of 6 mm in the case where the recommended drumfilter is used. For discfilter in primary applications without chemical dosing, coarse screening of 1-2 mm in diameter is recommended. For both cases it is also recommended with grit and grease removal prior to the microscreen.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

5. Conclusions

Two microscreen configurations (Drumfilter and Discfilter) have been optimized in Powerstep for their use in primary treatment applications. It was confirmed that Drumfilters provide a more robust performance in all conditions and it should be considered as the preferred option for primary treatment out of the microscreen configurations tested here. Discfilters can be recom-mended in sites where footprint is a key factor. However, special care has to be taken with the pre-treatment and the accumulation of sludge in the Discfilter drum (especially in the case where flocculating agents are dosed upstream). Long-term high-resolution data has demon-strated that the filters can be maintained clean with filtrate, self-cleaning nozzles, and back-wash pressures between 4-8 bar, which reduces the operation and maintenance needs for the installation. Chemical cleaning (every 1-3 months, depending on raw wastewater feed) is cru-cial in order to minimize energy use and sludge production. These cleanings can be fully automated without draining the unit and require only 25-30L of chemicals per cleaning cycle for the biggest microscreens available. Chemical cleanings are required more often in applications where both coagulant and polymer are dosed upstream to control COD extraction. Regular high pressure cleaning at 80 bar can help recovering 10-20% of the treatment capacity if pre-formed regularly. 6 mm screening, and sand and grit removal are considered to be necessary for a good operation of the Drumfilter. Discfilters would additionally require 1mm fine screening upstream. Both 100 and 40 micron filter clothes yielded similar performances in terms of remov-al, but it is expected that the more open mesh will yield filtration rates 50% higher for the same type of microscreen.

The potential to harvest COD from wastewater was clearly maximized when flocculating agents were dosed upstream both microscreen configurations. Stable reductions between 50 and 60% were obtained with different degrees of chemical dosing (1-5 mg-Al/L and 3 mg-poly/L). These figures represent 90-100% of the maximum COD extraction yields considering a typical fractionation of the soluble and particulate COD for this type of wastewater (Henze et al., 2008). Extraction without chemical addition recovered only 20-30% of the total organic car-bon. This increase in the extraction yields with flocculant addition together with the short resi-dence times in the system can contribute to a speedy optimization of the energy recovery at the plant in periods where it is economically interesting to have a higher the energy production.

The 90%-ile hydraulic loading of the filter was 15 m3/h and the 90%-ile TSS concentration 400 mg/L. The Drumfilter installed in Westewitz (40 m pore size) used less than 20% of the maximum installed capacity during peak loading conditions without any chemical addition upstream (i.e., the unit is theoretically able to treat up to 5 times more flow: 75 m3/h). Less than 10% of the capacity was used during peak loading conditions when a polymer was dosed upstream the filter (i.e., the unit theoretically could have taken up to 150 m3/h with enhanced polymer pre-treatment). A footprint of about 19 m2 would have been required by a primary clarifier to treat the same maximum flow without chemicals, assuming an aggressive design loading rate of 4 m/h (Metcalf & Eddy Inc et al., 2002). The whole Powerstep treatment system (including chemi-cal storage, and reaction tanks) could be fitted in the footprint of a 20 feet container, which has an area of 15 m2 (80% of the clarifier footprint). The area of the Drumfilter used was 6 m2, only 30% of the footprint required by a clarifier. The footprint could have been minimized even further if a 100 µm cloth had been used instead. Primary clarifiers require residence times of 2-3 hours in order to reach TSS removals around 50%, meaning that large construction volumes are required (typical depths go up to 3 meter). On the contrary, the Powerstep carbon extraction concept allows for modular design, easy installation costs, and very short residence times that allow to perform robust, controlled, and dynamic carbon recovery, as demonstrated here.

In summary, the full-scale demonstration sites built and operated during the length of this pro-ject helped demonstrating that robust, efficient, flexible, and compact primary treatment can be performed by using state of the art microscreen technology.

The project “Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration” (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

6. References

Henze, M., van Loosdrecht, M.C.M., Ekama, G.A., Brdjanovic, D., 2008. Biological wastewater treatment. IWA publishing.

Kängsepp, P., Väänänen, J., Örning, K., Sjölin, M., Olsson, P., Rönnberg, J., Walleback, F., Cimbritz, M., Pellicer-Nàcher, C., 2016. Performance and operating experiences of the first scandinavian full-scale discfilter installation for tertiary phosphorus polishing with preceding coagulation and flocculation. Water Pract. Technol. 11, 459–468. https://doi.org/10.2166/wpt.2016.040

Metcalf & Eddy Inc, Tchobanoglous, G., Burton, F.L., Stensel, H.D., 2002. Wastewater Engineering. Treatment and Reuse, 4th ed. McGraw-Hill, New York.

OEWA (2012) Betriebshandbuch OEWA

Remy, C., Boulestreau, M., Lesjean, B., 2014. Proof of concept for a new energy-positive wastewater treatment scheme. Water Sci. Technol. 70, 1709–1716. https://doi.org/10.2166/wst.2014.436

Rusten, B., Odegaard, H., 2006. Evaluation and testing of fine mesh sieve technologies for primary treatment of municipal wastewater. Water Sci. Technol. 54, 31–38.

Siegrist, H., 2008. Anammox brings WWTP closer to energy autarky due to increased biogas production and reduced aeration energy for N-removal. Water Sci. Technol. Agricultur, 383.

Väänänen, J., Cimbritz, M., la Cour Jansen, J., 2016. Microsieving in primary treatment: effect of chemical dosing. Water Sci. Technol.

7. Appendix 1: Correlation factors from online sensor data (Westewitz WWTP)

Correlation factors have been calculated from the comparison of grab samples and logged online turbidity data (influent and effluent of the filter) for evaluation of the filter performance in terms of TSS-, COD- and TP-removals. The influent grab samples were collected in the influent pumping pit upstream the filtration plant and the effluent grab samples from the filter tank effluent.

Total suspended solids

The correlation between influent and effluent filter turbidity and TSS is seen in Figure 76. The linear correlation was calculated without an ordinate, as it was expected that solids were the main contributors to turbidity in the samples. The correlation factor for inlet water was above 1, suggesting that particles contributing to turbidity for this water have a higher specific mass than the particles in the filtrate.

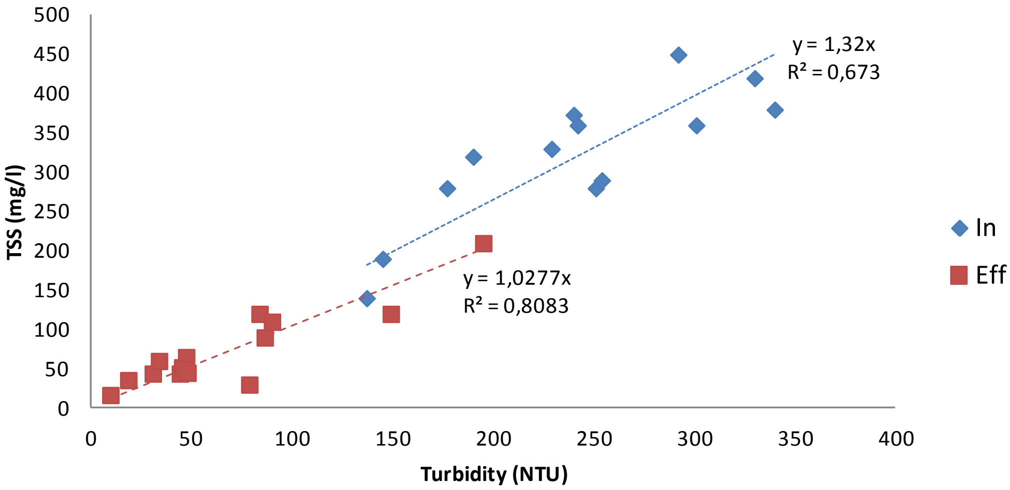

Figure 76: Correlation between turbidity and TSS from grab samples for influent and effluent of the filter

Total COD

The correlation between influent turbidity and total COD is seen in Figure 77. The intersection point with the y-axis gives an estimation of the dissolved fraction of the influent total COD, which in this case is 190 mg O2/l, slightly lower than expected for medium-low strength wastewater (Henze et al., 2008).

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

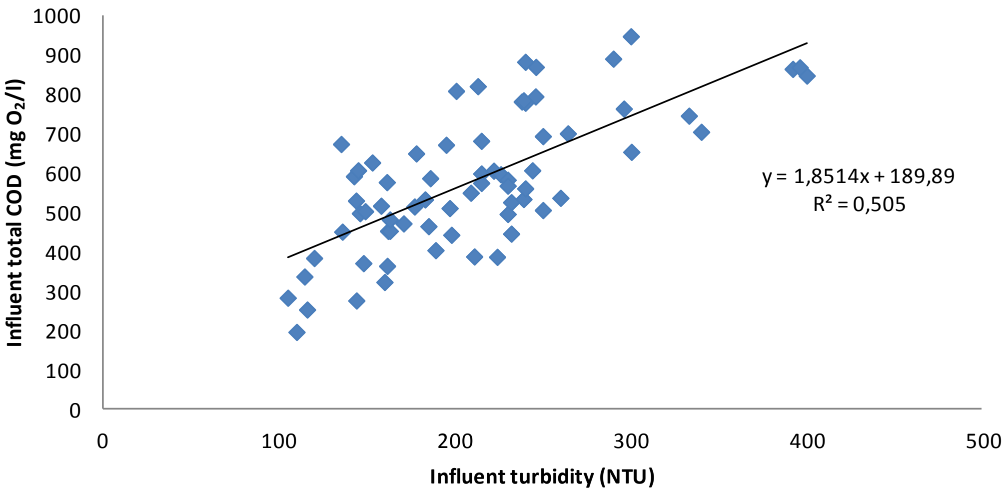

Figure 77: Correlation between influent turbidity and total COD from grab samples from the influent pumping pit.

When dosing chemicals, especially coagulant, it is possible to have some of the colloidal fraction of COD converted to particulate COD, which then can be removed by the filter. Due to this, the effluent correlation between turbidity and COD in Figure 78 has been split into three different operation settings:

- No chemicals,
- Flocculation
- Coagulation & flocculation.

For the correlations where chemicals have been added, the coagulant dose applied were in the range of 1-14 mg Me^{3+}/l (average of 2.2 mg Me^{3+}/l). Corresponding polymer doses were in the range 0.5-8 mg/L (average of 3.1 mg/l).

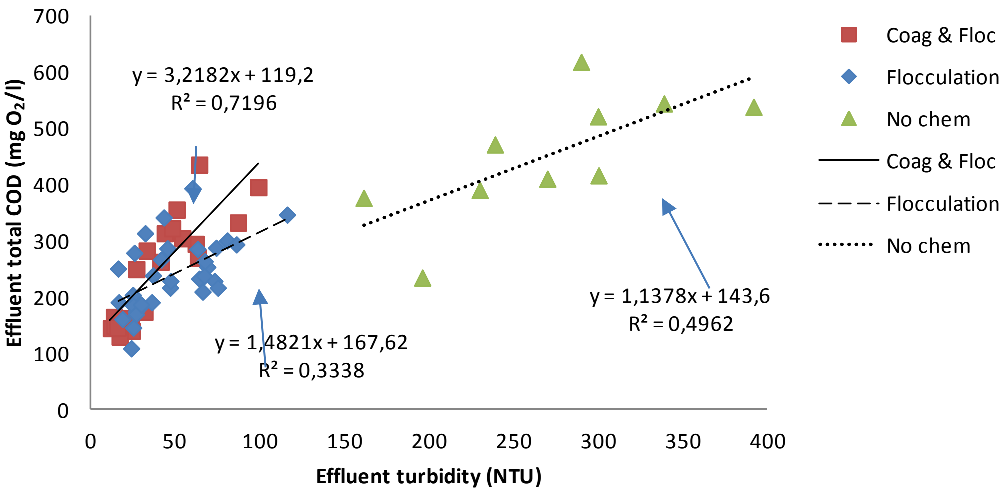

Figure 78: Correlation between effluent turbidity measured with online sensor and Total COD from grab samples collected from the same point for the different dosing strategies.

Total Phosphorus

The correlation between influent turbidity and total Phosphorus is seen in Figure 79. The intersection point with the y-axis gives an estimation of the dissolved fraction of the influent TP, which in this case is 7.8 mg PO4-P/l, in the range of what is expected for medium-low strength wastewater (Henze et al., 2008).

By adding a coagulant it is possible to convert a substantial part of the dissolved Phosphorus into particulate Phosphorus, which then can be removed by the filter. Due to this reason the effluent correlation between turbidity and TP in Figure 80 has been split into three different operation settings:

- No chemicals
- Flocculation
- Coagulation & flocculation.

The coagulant and polymer doses applied, when relevant, were the same as for total COD described above Figure 78.

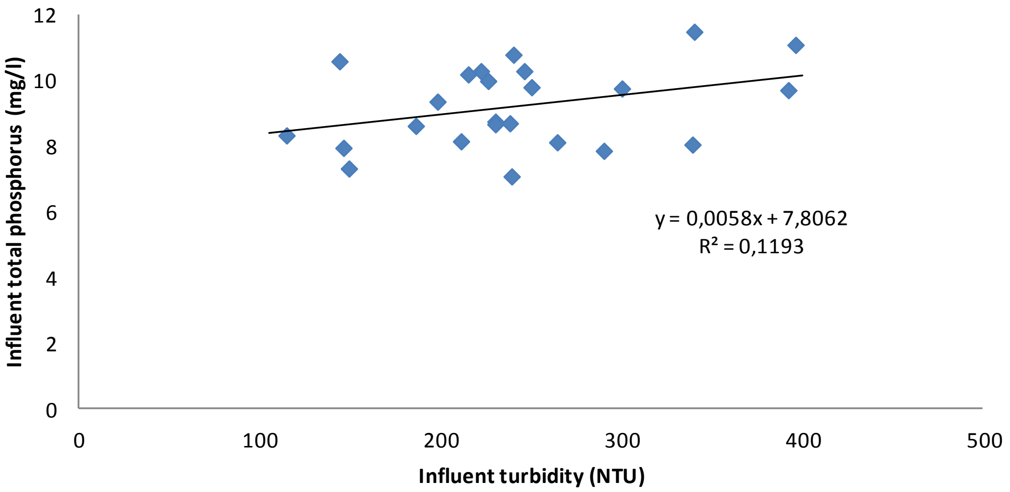

Figure 79: Correlation between influent turbidity measured with online sensor and total Phosphorus from grab samples from the same point.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

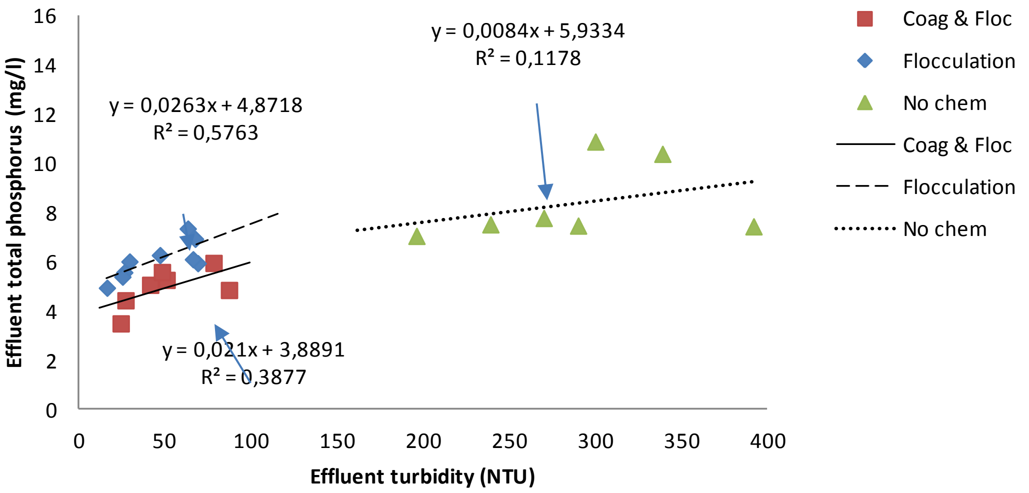

Figure 80: Correlation between effluent turbidity measured with online sensor and total Phosphorus from grab samples collected from the same point for the different dosing strategies.

Energy demand HDF

Three energy meters were installed, one for the whole plant and one for each of the heaters installed in each of the two containers. As the influent flow into the primary treatment was discontinuous and the filter only uses energy for backwashing, the energy consumption of the auxiliary equipment (mixers, polymer station, and dosing pumps) could be estimated when the drumfilter was out of operation. By subtracting these data, the energy consumption of the drumfilter correlated well with backwash frequency of the filter (Figure 81), which confirms that the backwash frequency of the drumfilter can be used for calculation of the energy consumption of the microscreen.

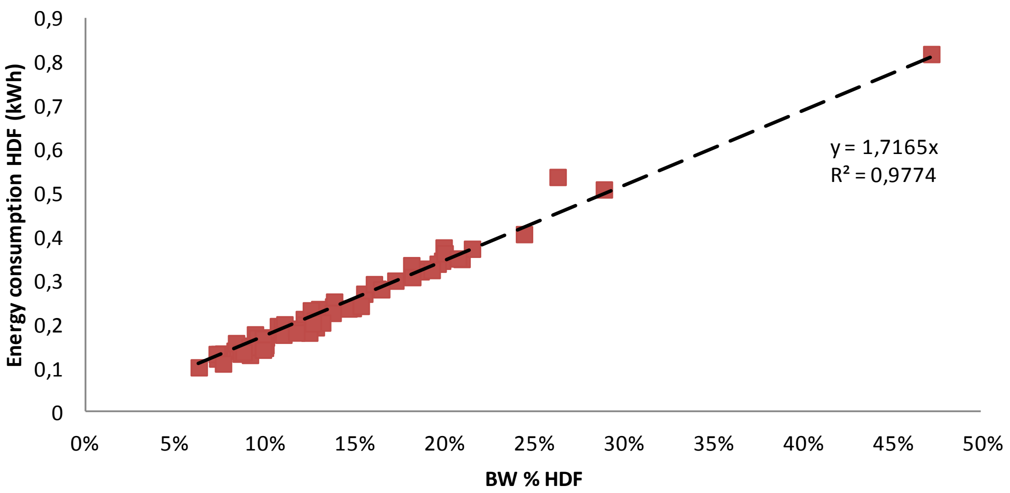

Figure 81: HDF energy demand correlation with the BW% used for estimation of the energy demand required by the filter when no chemicals were added. The backwash pressure was controlled with a seat valve and did not affect the energy demand.

8. Appendix 2: Correlation factors for use of online sensor measurements (Sjölunda WWTP)

Total suspended solids

The correlation between influent and effluent turbidity and TSS for the pilot plant is seen in Figure 82. The linear correlation was calculated without an ordinate, as it was expected that solids were the main contributors to turbidity in the samples. The correlation factor for inlet water was significantly higher than for the effluent water with no chemicals added (Figure 83), suggesting that particles contributing to turbidity for this water have a higher specific mass than the particles in the filtrate. However, the correlation factor for the effluent turbidity and TSS after chemical treatment suggests a similar specific weight of the particles in both influent and effluent, due to chemical addition and post-flocculation.

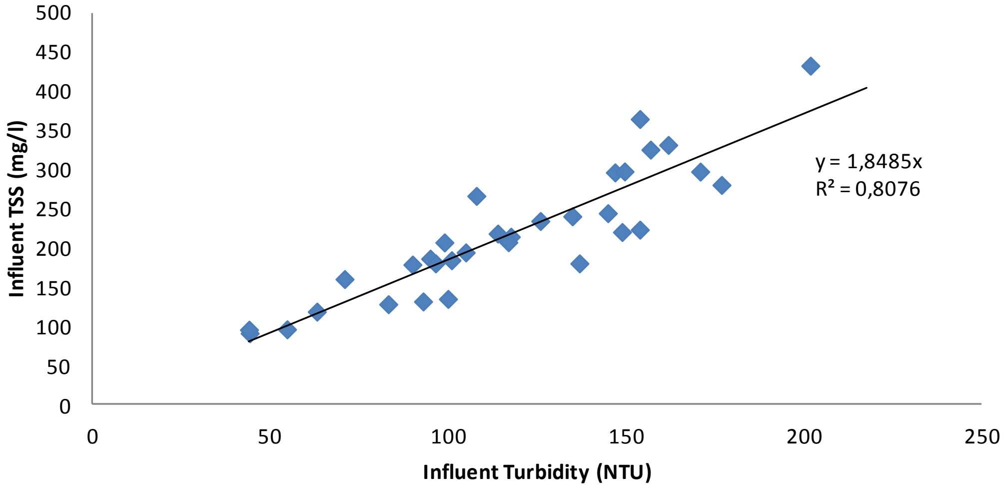

Figure 82: Correlation between influent turbidity at the pumping pit and TSS from grab samples

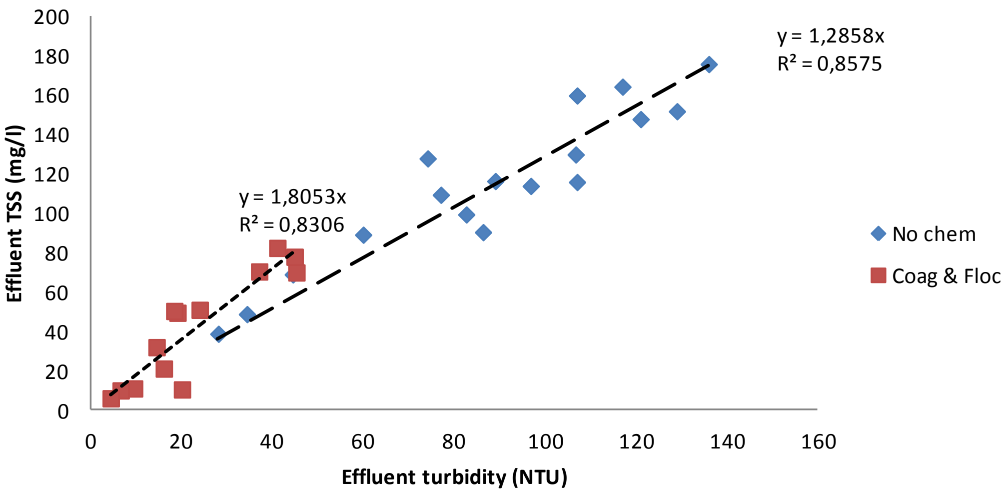

Figure 83: Correlation between effluent turbidity measured on the discfilter effluent with TSS-data from grab samples from the same sampling point

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Total COD

The correlation between influent turbidity and total COD is seen in Figure 84 . The correlation is calculated to be representative for the typical influent turbidity range and the intersection point with the y-axis cannot be used for estimation of the dissolved fraction of COD.

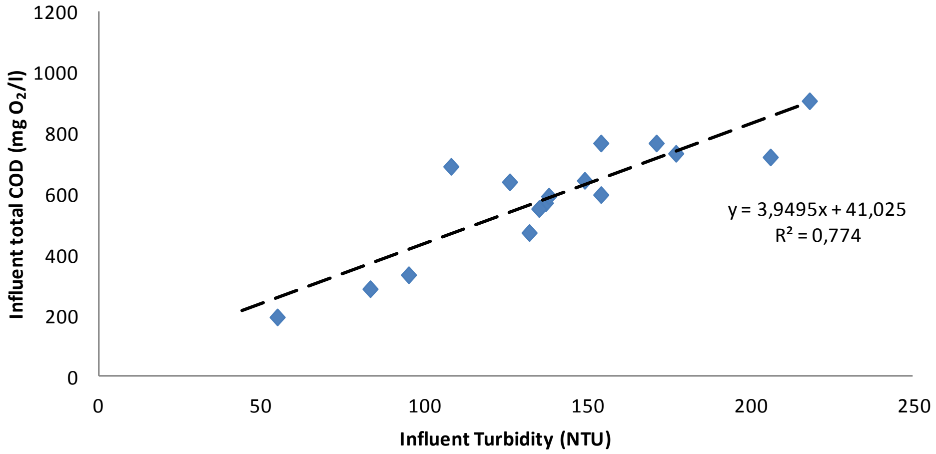

Figure 84: Correlation between influent turbidity measured with online sensor at the pumping pit and total COD from grab samples from the same point.

When dosing chemicals, especially coagulant, it is possible to have some of the colloidal fraction of COD converted to particulate COD, which then can be removed by the filter. Due to this, the effluent correlation between turbidity and COD in Figure 85 has been split into two different operation settings: no chemicals and coagulation & flocculation (coagulant dosing range 0,6-14,5 mg Al3+/l and polymer dosing range 0,3-5,9 ppm). Results show that turbidity has a higher impact on the total COD in the effluent when no chemicals are added in the system, suggesting that a higher fraction of the COD can be removed with chemical pre-treatment.

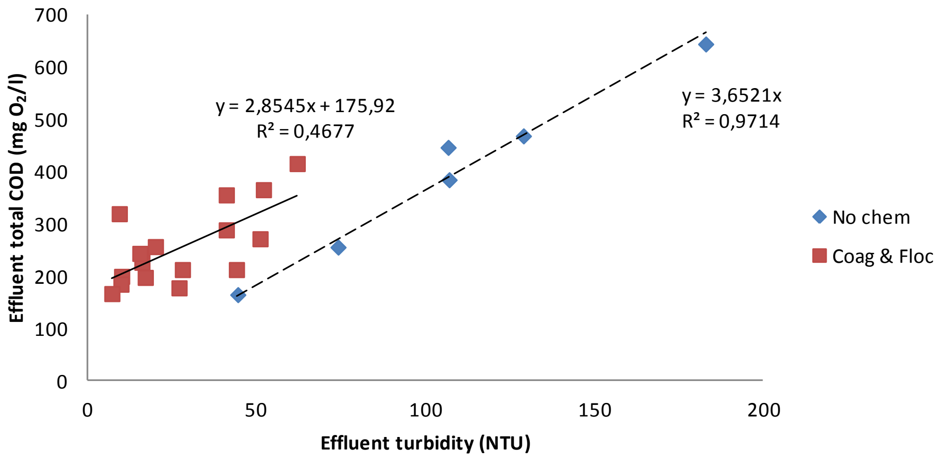

Figure 85: Correlation between effluent turbidity measured with online sensor on the effluent side inside the discfilter with total COD-data from grab samples from the same sampling point with and without chemical addition.