



Master thesis
in Environmental Sciences and Engineering

**Evaluation of chemically-enhanced microsieving
as primary treatment of municipal wastewater**

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Abstract

The growing urge to cut greenhouse gas emissions in all sectors to limit climate change requires the development of solutions to reduce the environmental impact of wastewater treatment plants (WWTPs), notably their use of energy. Currently, while some biogas can be produced through anaerobic digestion of the sludge produced in WWTPs, these installations usually are net consumers of energy due to the need for aeration to perform the biological oxidation of carbon and nitrogen. One of the possibilities explored to reduce the impact of WWTPs is to increase the efficiency of the primary treatment with the objective to transfer a maximum amount of organic matter into anaerobic digestion to increase the production of biogas while reducing the loads transferred to the biological treatment. To this end, some studies have shown that microsieves, which constitute an attractive alternative to primary settlers, could be used in combination with chemical-enhancement. However, as knowledge remains limited regarding this kind of system, this work aimed to understand the extent to which the performances of a microsieve could be increased through chemical-enhancement. Furthermore, this work also focused on the effect of microsieving with and without chemical-enhancement on sludge properties such as biochemical methane potential (BMP) and cellulose content. It is worth noting that the latter tends to receive growing interest as, beyond anaerobic digestion, alternative sludge valorization pathways aiming to recover cellulose (which comes from toilet paper) are emerging.

The results showed that while microsieving without chemical-enhancement resulted in removal rates of 50% for total and volatile suspended solids (TSS and VSS) and 30% for chemical oxygen demand (COD), removal rates of 80% for TSS and VSS and 55% for COD could be obtained with chemically-enhanced microsieving. Regarding sludge properties, results showed that without chemical-enhancement microsieving produces sludge with increased volatile solids (VS) content, BMP, and cellulose content compared to primary settling. With chemical-enhancement, these effects are reduced and may even result in lower values than those obtained with primary settlers. However, linking capture performances with sludge properties allowed to estimate that, compared to primary settling, microsieving without and with chemical-enhancement could lead to increases of respectively 10% and 35% in methane production or of respectively 20% and 60% in cellulose recovery. Moreover, chemical-enhancement could reduce by 60% the amounts of TSS and VSS transferred to the biological treatment and by 35% the amount of COD. This shows that working on the improvement of wastewater primary treatment has a great potential to improve the performance of WWTPs in terms of energy balance and resource recovery.

Glossary

BMP	Biochemical Methane Potential
CEPT	Chemically-enhanced Primary Treatment
COD	Chemical Oxygen Demand
DS	Drum Screen
GHG	Greenhouse Gas
HRT	Hydraulic Residence Time
IPCC	Intergovernmental Panel on Climate Change
IQR	Interquartile Range
PS	Primary Settler
RBF	Rotating Belt Filter
TS	Total Solids
TSS	Total Suspended Solids
VS	Volatile Solids
VSS	Volatile Suspended Solids
WW	Wastewater
WWTP	Wastewater Treatment Plant

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1 Introduction

As the IPCC recently stated that limiting global warming to 1.5°C (even 2°C) involves in all modelled pathways ‘rapid and deep and in most cases immediate GHG emission reductions in all sectors’ [1], the water sector must also work towards finding solutions to decarbonise. Indeed, in many cases wastewater treatment plants (WWTPs) currently in operation are net consumers of energy. As described by Nowak et al. [2], historically settling was usually the only treatment step for wastewater, resulting in the production of sludge that could then be anaerobically digested to produce biogas. At this stage, more energy could be gained than the energy required to run the plant. Later on, biological treatment was introduced as a second treatment step to achieve higher carbon removal performances. This step however requires energy to supply oxygen to the wastewater through aeration for the oxidation of carbon. Its implementation therefore reduced the positive energy balance of WWTPs. In addition, WWTPs are now usually required to eliminate ammonia. This requirement led to the extension of the biological treatment to oxidize ammonia through nitrification. Consequently, aeration needs increased and led to the current situation where many WWTPs have higher energy requirements than what can be produced with the biogas obtained from the sludge.

In recent years, various projects, notably the POWERSTEP project funded by the European Union, have been testing different approaches to turn WWTPs into energy-producing facilities. Among the avenues explored, some efforts are made to increase the efficiency of the primary treatment with the objective to ‘transfer a maximum amount of organic matter into anaerobic digestion to produce biogas’ [3], which at the same time would reduce the amount of energy consumed by aeration during the biological treatment [4]. To this end, several options may be considered. As already mentioned, settling is the conventional technology for the primary treatment of wastewater. And the efficiency of this process can be enhanced by adding chemicals to the wastewater upstream of the settling tank, ‘allowing small particles to form larger flocs and subsequently achieving higher sedimentation velocities’ [5]. However, even if primary settlers are simple to operate and require low maintenance, their main drawback is the large land space they occupy [5]. As many cities continue to grow, which implies that the amount of wastewater to treat increases while space for additional treatment facilities becomes limited, new technologies need to be employed to increase the treatment capacity of existing WWTPs without taking more land space. To this end, microsieves have been developed and can be used as an alternative to primary settlers [6]. Their working principle is based on gravity-driven filtration of wastewater. They are designed as self-cleaning units able to ‘achieve high performance solid separation with minimal footprint and low energy consumption’ [7]. There

are three common types of microsieves: drum, disc, and rotating belt filters. The ‘*Compendium of best practices for advanced primary treatment*’ written by Schmidt & Schubert [5] provides an overview of these technologies regarding their working principle, removal efficiencies, operational indicators, as well as advantages and drawbacks that is briefly summarized in the following paragraph.

Drum and disc filters work similarly. As shown in Figure 1, wastewater enters in the center of the unit and solids accumulate on the filtration medium. This accumulation increases the filter resistance and leads to a rise of the water level in the central part of the sieve. When the water level difference between the central part and the tank that receives the filtered water reaches a defined threshold, the drum or discs start to rotate and water is sprayed on them to detach the solids that then fall into a funnel. In the case of rotating belt filters (RBFs), wastewater is fed on top of the filter. The wastewater progressively passes through the filter and solids accumulate on top of it. With the rotation of the belt, solids are continuously removed from it once they reach its extremity (see Figure 2). Even if drum and disc filters do not rotate continuously as RBFs do, it is important to understand that in both cases wastewater is constantly fed into the system and the filtration process occurs continuously. Microsieves constitute an attractive alternative to primary settlers as, to treat equivalent loads of wastewater, they require around 10 to 20% of the surface space taken by a primary settler while achieving equal or even better water clarification. Similarly to settling, microsieving performances can be enhanced by adding chemicals to the wastewater upstream of the filtration unit. A summary of the removal efficiencies in terms of total suspended solids (TSS) and chemical oxygen demand (COD) that can be expected using the different technologies available for the primary treatment of wastewater with and without chemical-enhancement is provided in Table 1.

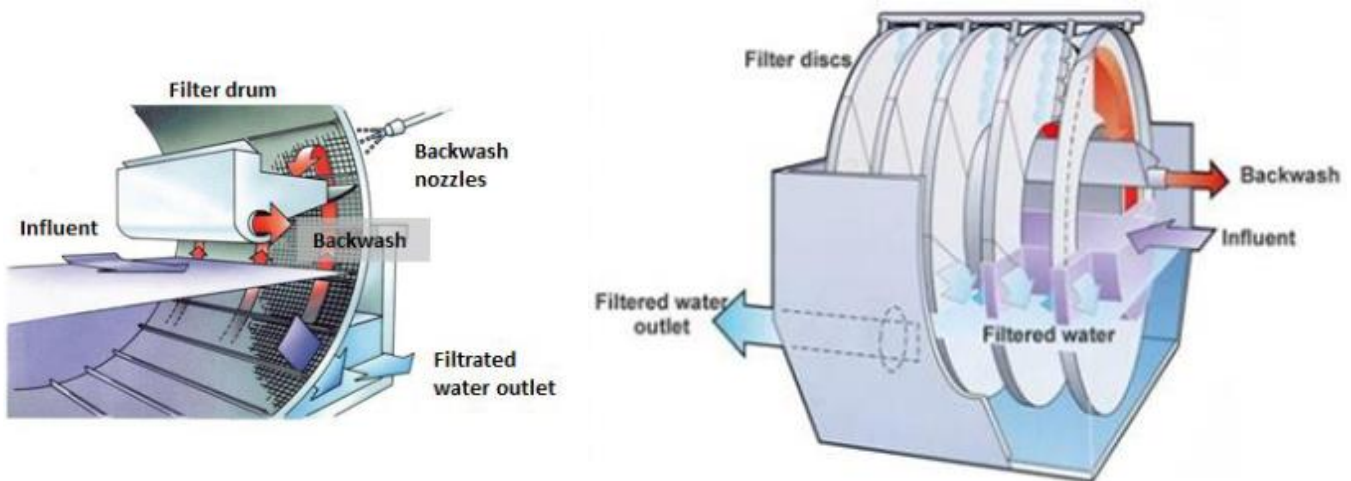


Figure 1 - Illustration of the working principle of drum (left) and disc (right) filters [5]

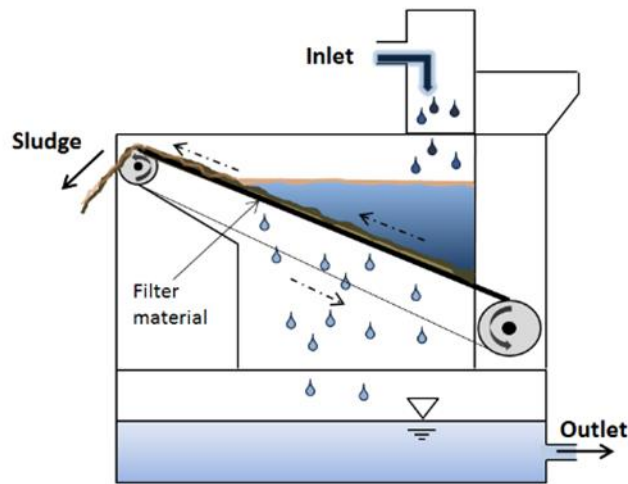


Figure 2 - Illustration of the working principle of a rotating belt filter [5]

Table 1 - Removal efficiencies associated with the different technologies available for the primary treatment of wastewater (with and without chemical enhancement) [5]

Technology	Chemical dosing	Removal efficiencies [%]	
		TSS	COD
Primary settler	-	40-70	25-35
	+	80-90	55-75
Drum and disc filter	-	40-60	Up to 60
	+	80-90	Up to 80
Rotating belt filter	-	25-60	15-40
	+	65-75	46

Regarding chemical-enhancement, there is a wide offer of coagulation and flocculation products on the market and preliminary tests must often be carried out to determine suitable combinations of products and their optimal dosing to achieve the highest possible removal rates. Historically, as described by Odegaard [8], metal salts (based on aluminium or iron) have been used as coagulant. However, they not only allow to achieve higher removal of solids but also lead to the precipitation of phosphate which considerably increases sludge production. When the removal of solids is the main concern, Odegaard showed that polymers could be used to replace, at least partially, metal salts and thus minimize sludge production. More recently, Vaananen et al. [6] recommended to use only cationic polymers for chemically-enhanced microsieving of wastewater if the objective is to optimize biogas production from the sludge.

As wastewater microsieving remains a recent technology, one of the goals of this work is to provide more knowledge on the performance of microsieves as an alternative to primary

settlers. This work focuses more specifically on chemically-enhanced microsieving using polymers. The polymers tested not only include synthetic (petroleum-based) products for which some knowledge already exists (Vaananen et al. [6], Rusten & Odegaard [9], and Rusten et al. [4]), but also bio-sourced products that could help WWTPs transition further towards more sustainable treatment processes and for which no studies are available.

Additionally, this work aims to provide more knowledge about the properties of the sludge that is obtained when microsieving wastewater. Indeed, as pointed out by Paulsrud et al. [10], even though several studies showed that microsieves can replace primary settlers and provide improved removal of solids, there is ‘very limited information about differences in sludge characteristics between the two primary treatment methods’. So far, some studies compared the difference in terms of methane production between sludges from primary settlers and microsieves (Paulsrud et al. [10], Sarathy et al. [11], Ghasimi et al. [12], and Bahreini et al. [13]) and Rusten et al. [4] looked at the effect of chemical-enhancement on methane production but in all cases the microsieves used were RBFs. On another hand, a few studies focused on the cellulose content of the sludge depending on the type of primary treatment (Ruiken et al. [14], Gupta et al. [15], and Ahmed et al. [16]). The latter showed that cellulose (which comes from toilet paper) is a major constituent of wastewater as it represents approximately one-third of the influent TSS in raw municipal wastewater. It also showed that while settling and microsieving (using RBFs) achieved ‘similar and very high cellulose capture rates (> 80%)’, RBFs were able to ‘selectively capture cellulose over TSS’ (cellulose represented 35% of the TSS captured by RBFs while it represented 17% in the sludge from primary settlers). This feature is interesting as, beyond anaerobic digestion, sludge from microsieves could be valorized differently with the aim of recovering cellulose for the production of new products such as bioplastics, biofuels, and building materials [15], [16].

In a nutshell, the type of primary treatment applied to wastewater has implications in terms of solids removal, energy consumption of the biological treatment, and possible sludge valorization pathway. This work therefore aims to bring more knowledge regarding the use of microsieves, specifically drum screens (DS), for the primary treatment of wastewater in the context where WWTPs need to reduce their GHG emissions and become more sustainable. To this end, the following research questions are addressed in this study:

- To what extent can organic substrates in the particulate form be captured during chemically-enhanced microsieving of municipal wastewater?
- Do the solids captured with a microsieve have a different composition than solids captured with conventional primary settlers?

2 Material and methods

2.1 Microsieving performance tests

During this work, the performance of microsieving as primary treatment was tested under five different conditions. First, microsieving was performed with no addition of chemicals. The four other conditions included the use of chemicals with the aim of improving the capture performances of the microsieve. These chemically-enhanced treatments all included the use of a coagulant followed by a flocculant. On the one hand, synthetic chemicals were tested using two different dosages: 15 mg/l of coagulant + 3 mg/l of flocculant and 20 mg/l of coagulant + 6 mg/l of flocculant. On the other hand, the same dosages were then tested using bio-sourced chemicals. The choice of these two combinations of chemical concentrations was based on the work carried out by Camila Morales Undurraga during her internship at Eawag under the supervision of Dr. Nicolas Derlon [17]. During this internship, jar tests were performed (as described in section 2.3.5) to determine the optimal concentration ranges that improve solids removal from the wastewater. Table 2 summarizes the five conditions that were tested and Table 3 provides detailed information about the chemicals used. Regarding liquid chemicals, it is important to note that the dosages were calculated based on the active compound concentration of each product.

Table 2 - Summary of the tested conditions

Abbreviation	Description
No Chem	Microsieve with no use of chemicals
Synth 15+3	Microsieve + synthetic chemicals : 15 mg/l of coagulant + 3 mg/l of flocculant
Synth 20+6	Microsieve + synthetic chemicals : 20 mg/l of coagulant + 6 mg/l of flocculant
Bio 15+3	Microsieve + bio-sourced chemicals : 15 mg/l of coagulant + 3 mg/l of flocculant
Bio 20+6	Microsieve + bio-sourced chemicals : 20 mg/l of coagulant + 6 mg/l of flocculant

Table 3 - Information regarding the chemicals

Product type	Product reference (manufacturer)	Description	Active compound concentration [%] ¹
Synthetic coagulant	FLOQUAT FL 4440 (SNF)	Liquid polyDADMAC (cationic polymer)	40%
Synthetic flocculant	FLONEX SFC 100 DF (SNF)	Liquid cationic flocculant	25%
Bio-sourced coagulant	FLOQUAT FL 5323 (SNF)	Liquid tannin-based coagulant	25%
Bio-sourced flocculant	Empresol N (Emsland Group)	Starch-based cationic powder	-

¹ Information provided by the manufacturer.

For each tested condition, the same measurement approach was applied. Usually, each condition was tested over a duration of 24 hours in order to capture various wastewater compositions and pollutant loads. The capture performances were evaluated based on the measurement of total suspended solids (TSS), volatile suspended solids (VSS), and chemical oxygen demand (COD) removal rates at a regular interval during each test. To compute the removal rates, water samples were taken at both the inlet and outlet of the system using two automatic water samplers (Liquistation CSF48, Endress+Hauser). The samplers were set to take hourly composite samples based on 6 samplings of 150 ml with a sampling interval of 10 minutes. TSS and VSS measurements were always carried out for every hour, while COD measurements were performed with an interval of 2 to 3 hours. Additionally, sludge samples were taken to monitor several sludge properties. As this type of sample had to be taken manually, sampling was performed only during the day. For almost every test, 6 samples were taken at around 7:30 am, 9:30 am, 11:30 am, 1:30 pm, 3:30 pm, and 5:30 pm. In one case², samples were taken hourly between 11:30 am and 5:30 pm. For every sludge sample, total solids (TS) and volatile solids (VS) measurements were performed and the cellulose content was quantified. Moreover, at least one sample was usually kept (refrigerated or frozen) to later perform one biochemical methane potential (BMP) measurement. All analytical methods to perform TSS, VSS, COD, TS, VS, cellulose content, and BMP measurements are described in section 2.3. A schematic of the system (further described in section 2.2) with a summary of the measured parameters is provided in Figure 3. All tests were carried out in the experimental hall of Eawag where the wastewater from the sewage network of the city of Dübendorf (Switzerland) is pumped and can be used for experiments. Last but not least, Table 4 shows the exact number of measurements that were performed during each test.

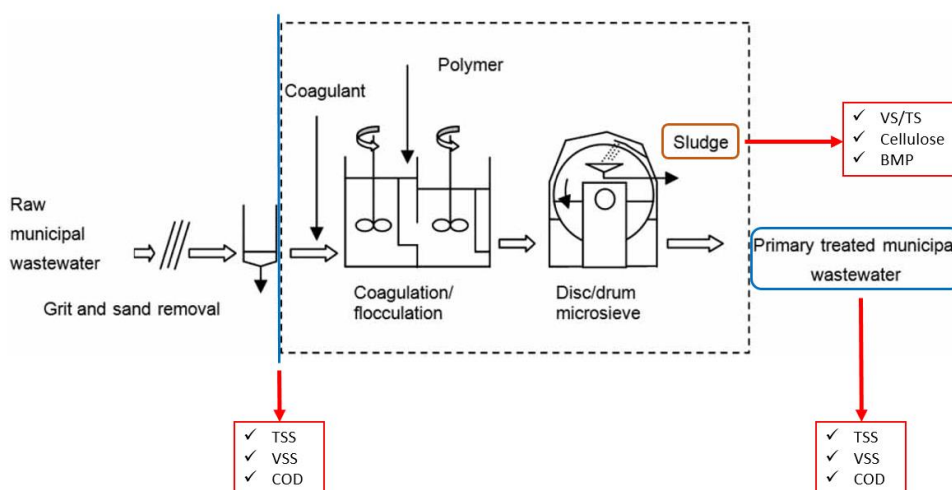


Figure 3 - Parameters measured for each condition (adapted from [6])

² Test carried out on 11.04.2022 (see Table 4).

Table 4 – Number of samples and measurements obtained for each tested condition
 (For each parameter, the first number refers to the number of valid measurements that were obtained while the second number refers to the number of samples that were taken. The ‘*’ sign refers to BMP measurements for which samples were taken but not analysed.)

Condition	Start time	Duration [h]	TSS + VSS	COD	VS/TS + cellulose	BMP
No Chem	<i>Total</i>	22	22/22	11/12	11/11	1/1
	11.04.2022 11am	7	7/7	6/7	7/7	0/0
	21.04.2022 8pm	15	15/15	5/5	4/4	0/0
	23.05.2022 11am	-	-	-	-	1/1
Synth 15+3	<i>Total</i>	42	41/42	17/17	8/8	1/1
	04.05.2022 6pm	24	23/24	8/8	6/6	0/0
	07.07.2022 6pm	18	18/18	9/9	2/2	1/1
Synth 20+6	13.06.2022 11am	24	24/24	12/12	6/6	1/1
Bio 15+3	20.06.2022 10am	24	24/24	10/12	6/6	*/1
Bio 20+6	27.06.2022 11am	24	24/24	12/12	6/6	*/1

2.2 Experimental setup

The setup first consisted of a pump bringing a constant flow rate of 1 m³/s of wastewater into the system. The wastewater then entered the coagulation tank (where the coagulant was added and mixed with the wastewater) which was followed by the flocculation tank (see Figure 4). The flocculant was added to the wastewater at the outlet of the coagulation tank. In the flocculation tank, gentle mixing conditions were applied and flocs were expected to form. The total hydraulic residence time (HRT) in the coagulation and flocculation tanks was 10 minutes.

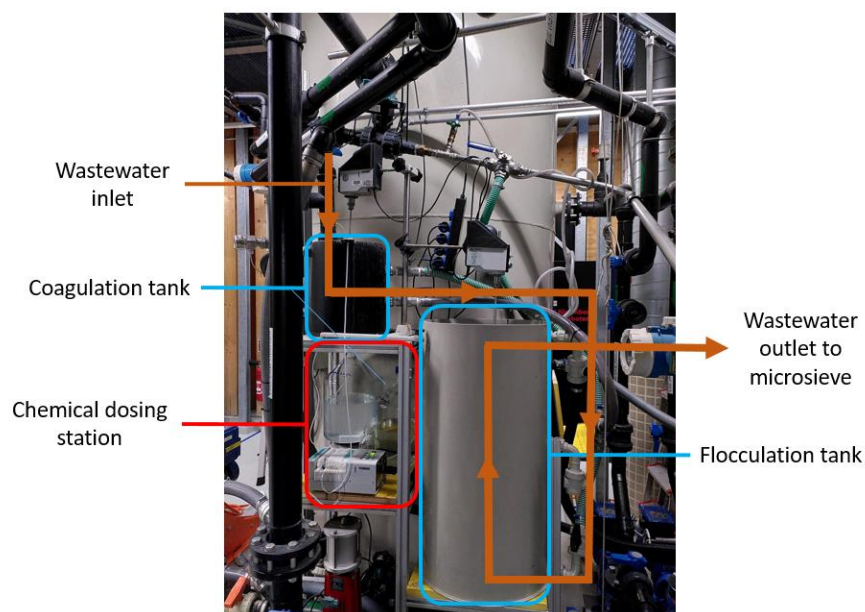
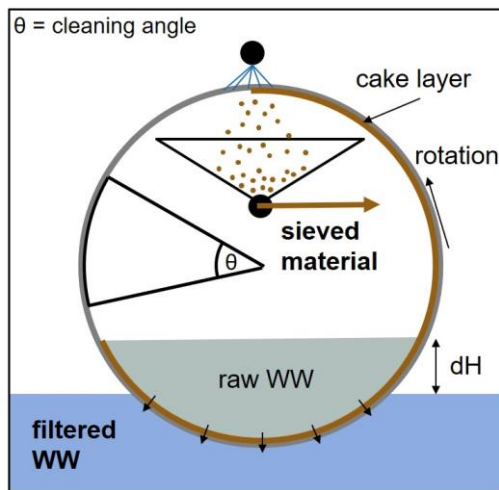
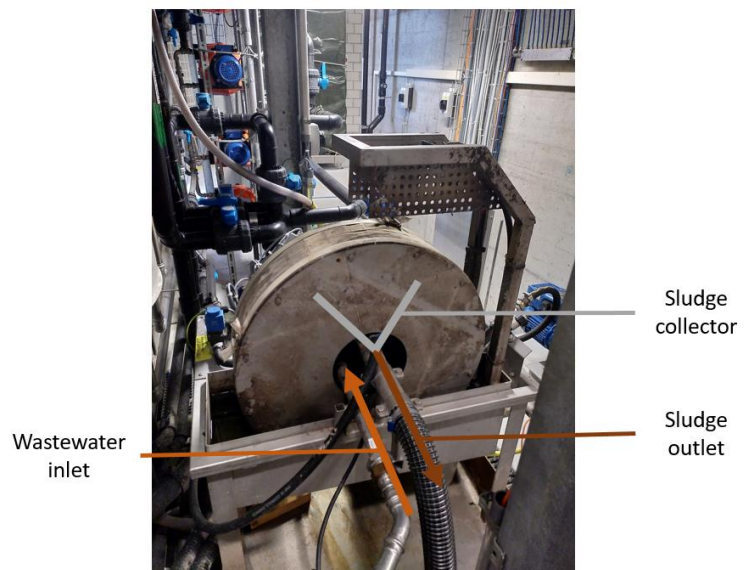


Figure 4 - Coagulation and flocculation tanks

The wastewater then flowed to the microsieve. The microsieve was a pilot-scale drum screen (HUBER Drum Screen LIQUID-Mini) that has a diameter of 0.6 m, an effective length of 0.08 m, and was operated with a mesh size of 100 μm . As shown in Figure 5, the wastewater enters the sieve at its center. It then flows to the bottom where solids are retained on the mesh while the water passes through it. As solids accumulate on the mesh, the latter clogs and the water level inside the drum rises. When the difference in water level between the inside and the outside of the drum reaches a defined threshold, a cleaning cycle starts. During this process, the drum rotates to bring the solids to the top where a hose sprays water on the mesh and the solids detach and fall into a funnel. The mix of solids and cleaning water forms a sludge that then flows out of the drum. By removing the solids from the mesh, the cleaning allows the water level inside the drum to drop. In addition to the regular cleaning cycle, a high-pressure cleaning cycle would start in case the water level difference reaches a second threshold (higher than the first one). Water is then sprayed at a higher pressure, which allows for a better cleaning of the mesh. All tests were carried out using the same cleaning settings. The regular cleaning was triggered with a water level difference of 13 cm and would last 15 seconds with a rotation speed of the sieve of 10 Hz. The threshold was 15 cm for the high-pressure cleaning, with a duration of 30 seconds and a rotation speed of 20 Hz.



a) Diagram illustrating the working principle of a drum screen [18]



b) Pilot-scale drum screen (without the case that covers it during its operation)

Figure 5 – Drum screen

2.3 Analytical methods

2.3.1 Solids

Measurements regarding solids in wastewater and sludge were carried out based on the ‘*Standard Methods For the Examination of Water and Wastewater*’ established by the American Public Health Association [19].

More precisely, TS measurements were carried out based on method 2540 B using samples of 100 ml. TSS measurements were based on method 2540 D using samples of 500 ml and glass-fiber filters with a retention capacity of 1.4 μm (Macherey-Nagel MN GF-4). Drying duration varied but was always longer than 12 hours as samples were always left overnight in the oven.

VS and VSS measurements were carried out based on method 2540 E with an ignition duration of approximately 60 minutes.

2.3.2 Chemical Oxygen Demand

COD measurements were carried out using cuvette tests LCK114 from Hach Lange GmbH.

2.3.3 Cellulose

The method used for the quantification of cellulose in sewage sludges was originally developed by Hurwitz et al. [20]. It relies on the reaction of cellulose with copper(II) hydroxide in alkaline solution (called ‘Schweitzer reagent’) which forms soluble complexes that can then be precipitated in an alcohol solution.

Based on the method developed by Hurwitz et al. [20] as well as a more recent version of it described in Gupta et al. [15], the following procedure was performed to determine the cellulose content of sludge samples using the Schweitzer reagent. First, the sample is pre-treated to remove proteins and other impurities. To this end, between 0.1 and 0.3 g of dried sample is diluted with 200 ml of distilled water in a 500 ml Erlenmeyer flask. Then 1.25 ml of 50% NaOH solution and 5 ml of diluted (1:5) antifoaming agent (Sigma-Aldrich, antifoam B emulsion) are added. The solution is boiled for 30 minutes using a reflux condenser to prevent solution losses. After cooling, it is poured into a 500 ml conical centrifuge bottle (VWR International) and diluted with 200 ml of distilled water. The solution is then centrifuged (Beckman J-6B) at 3000 rpm for 20 minutes. The pellet formed is kept aside while the supernatant is poured in another bottle and centrifuged again at 3000 rpm for 20 minutes. The supernatant is then discarded and the pellets from both centrifuge bottles are poured with 100 ml of Schweitzer reagent (which is prepared by adding 5.5 g of copper(II) hydroxide to 1 l of 30% ammonium hydroxide solution

and stirring the mixture for 30 minutes) in a 500 ml glass bottle. The solution is stirred for 60 minutes at 120 rpm allowing the cellulose fibers to form soluble complexes with the Schweitzer reagent. The solution is poured back into a 500 ml conical centrifuge bottle and centrifuged at 3000 rpm for 20 min. The supernatant is then transferred into another centrifuge bottle containing 300 ml of 80% ethyl alcohol. The solution is shaken, it then remains at rest for 30 minutes allowing the complexes to precipitate. The bottle is centrifuged at 3000 rpm for 20 minutes. The supernatant is discarded then the pellet is crushed in a mortar and washed with 1.25 HCl solution until the blue color of the precipitate disappears completely. The solution is then filtered on pre-washed and weighed 1.2 μm glass fiber filters (VWR International, grade 693 glass fiber filters). The filter is washed with distilled water followed by 10-20 ml of 80% ethyl alcohol. It is then left overnight in an oven at 105°C for drying and weighed. Finally, it is ignited for 1 hour in a muffle furnace at 550°C and weighed again. The cellulose content of the sample is calculated using the following equation:

$$\text{Cellulose content [\% TS]} = \left(\frac{\text{Weight of dried residue} - \text{Weight of ignited residue}}{\text{Weight of sample}} \right) * 100$$

Hurwitz et al. reported cellulose recovery of 97.5 and 98% in two tests [20], and Gupta et al. achieved 100% recovery in tests where toilet paper and α -cellulose were used as standards [15]. Additional tests with α -cellulose (Sigma-Aldrich) were also carried out during this work to ensure that the method described above yields satisfying cellulose recovery rates. These tests resulted in an average recovery rate of 87.7 ± 2.2 % (n = 6) (see Appendix A).

2.3.4 Biochemical Methane Potential

A BMP test aims to measure the ‘maximum amount of methane that can be recovered from a substrate per mass of substrate organic matter as volatile solids (VS) or chemical oxygen demand (COD)’ [21].

BMP tests were carried out using an AMPTS II Light device (Bioprocess Control Sweden AB) which offers an automated analytical procedure to measure the BMP of a substrate with real-time data logging and display of accumulated bio-methane volume and flow rate [22]. The device is composed of three units (see Figure 6). First, a sample incubation unit that accommodates six glass bottles (2000 ml) as anaerobic reactors. In each reactor, a mix of sludge sample and anaerobic inoculum continuously produces biogas³. Second, a CO₂-absorbing unit where the biogas produced in each reactor passes through an individual bottle containing an

³ As a reminder, biogas is a mixture of gases that primarily consists of methane (CH₄), carbon dioxide (CO₂) and hydrogen sulphide (H₂S).

alkaline solution (NaOH). The solution retains acid gas fractions (CO_2 and H_2S), therefore only allows CH_4 to reach the third unit. This last unit is the gas volume measuring device which ‘works according to the principle of liquid displacement and buoyancy’ [22]. When a defined volume of gas flows through the device, a digital pulse is generated and recorded by the integrated data acquisition system. A detailed BMP test setup procedure using the AMPTS II Light device can be found in the manual provided by the manufacturer [22].



Figure 6 - AMPTS II Light device (from right to left: the sample incubation unit, the CO_2 -absorbing unit, and the gas volume measuring device)

It is important to understand that, even though the device is composed of 6 reactors, only some of them actually contain a mix of sludge sample and inoculum during a BMP test. There are two reasons for this. On the one hand, one must be aware that the inoculum itself produces biogas. It is therefore necessary to determine the BMP of the inoculum so that it can be subtracted in the calculation of the sludge sample BMP. However, determining the inoculum BMP means that some reactors need to contain only inoculum during the test. On the other hand, it is recommended to carry out the test with a positive control which allows ‘validation of the inoculum activity with a standard substrate and compare it with its well-known nominal value’ [23]. The latest guidelines state to use micro-crystalline cellulose (CAS n°9004-34-6) as a positive control and that the results of a BMP test can only be validated if the BMP of cellulose is between $340 \text{ NL}_{\text{CH}_4}/\text{kg}_{\text{VS}}$ and $395 \text{ NL}_{\text{CH}_4}/\text{kg}_{\text{VS}}$ [24]. This recommendation therefore implies that some reactors are used to measure the BMP of cellulose as a positive control. At first, as described in the AMPTS II Light manual [22], the BMP tests were carried out using two reactors to determine the BMP of the inoculum, two reactors as positive controls (using micro-

crystalline cellulose), and two reactors to measure the BMP of the sludge sample. However, as the recommendations require to use triplicates to determine the BMP of the sludge sample [23], it was later decided to carry out the tests using three reactors for the sludge sample, two reactors to determine the BMP of the inoculum, and one reactor as a positive control (using micro-crystalline cellulose).

The following equations allow to calculate the BMP of a sludge sample. The first one is used to calculate the BMP of the inoculum. The second one is used to determine the BMP of any substrate: the sludge sample or, in the case of the positive control, micro-crystalline cellulose. As already explained, the inoculum BMP needs to be subtracted in the calculation of a substrate BMP. This is the reason why the variable $BMP_{inoculum}$ appears in the second equation.

$$BMP_{inoculum} = \frac{V_{inoculum}}{m_{inoculum} * \frac{VS_{inoculum}}{100}}$$

$$BMP_{substrate} = \frac{V_{substrate} - \left[BMP_{inoculum} * \left[(M - m_{substrate}) * \frac{VS_{inoculum}}{100} \right] \right]}{m_{substrate} * \frac{VS_{substrate}}{100}}$$

- $BMP \left[\frac{NmL}{g VS} \right]$ is the normalised⁴ volume of methane produced per gram of VS added
- $m [g]$ is the mass of substrate or inoculum present in the reactor
- $M [g]$ is the total mass (inoculum + substrate) present in the reactor
- $V [NmL]$ is the mean value of the accumulated volume of methane produced in the reactors
- $VS [%]$ is the percentage of volatile solids in the substrate or inoculum

Further information regarding the conditions under which the BMP tests were carried out is provided in Table 5.

Table 5 - BMP test conditions

Inoculum	The samples were taken from Neugut WWTP (Dübendorf, Switzerland) one day before the start of the BMP tests to allow for TS and VS measurements. During this time, the inoculum was stored at room temperature.
Substrate	When possible, the samples were also taken one day before the start of the BMP tests (allowing TS and VS measurements) and stored at 4°C. Otherwise, the samples were frozen at -20°C and thawed at 4°C.
TS and VS	TS and VS measurements were carried out as described in section 2.3.1
Working volume and VS ratio	The reactors (2000 ml) were always filled with 1500 g of solution respecting a ratio of 2 between the amount of VS from the inoculum and the amount of VS from the substrate.
Incubation	Mesophilic conditions (36°C) and mixing during 1 minute every 19 minutes.

⁴ 1.0 standard atmospheric pressure, 0°C and zero moisture content

2.3.5 Jar tests

Jar tests allow to test and compare the performance of coagulation and flocculation products and find the ideal concentrations that are required to reach a desired reduction in turbidity, TSS, or VSS.

Each test consisted in adding a certain amount of coagulant to 900 ml of wastewater and rapidly mixing it with a magnetic stirrer for 30 seconds. Then a certain amount of flocculant was added to the solution and the jar was moved to a flocculator (VELP Scientifica, Flocculation tester FC6S) to mix the solution during 10 minutes at 45 rpm. After mixing, the solution was left at rest for 15 minutes allowing the flocs to settle (see Figure 7). Finally, the jar was photographed and a sample of supernatant was collected to quantify turbidity, TSS, and VSS. For TSS and VSS measurements, the method is described in section 2.3.1. Turbidity was measured using a turbidimeter (Hach, TL2300 Tungsten Lamp Turbidimeter). Note that turbidity, TSS, and VSS measurements were also performed on the raw wastewater in order to be able to calculate the removal rates associated with the tested concentrations of coagulant and flocculant.

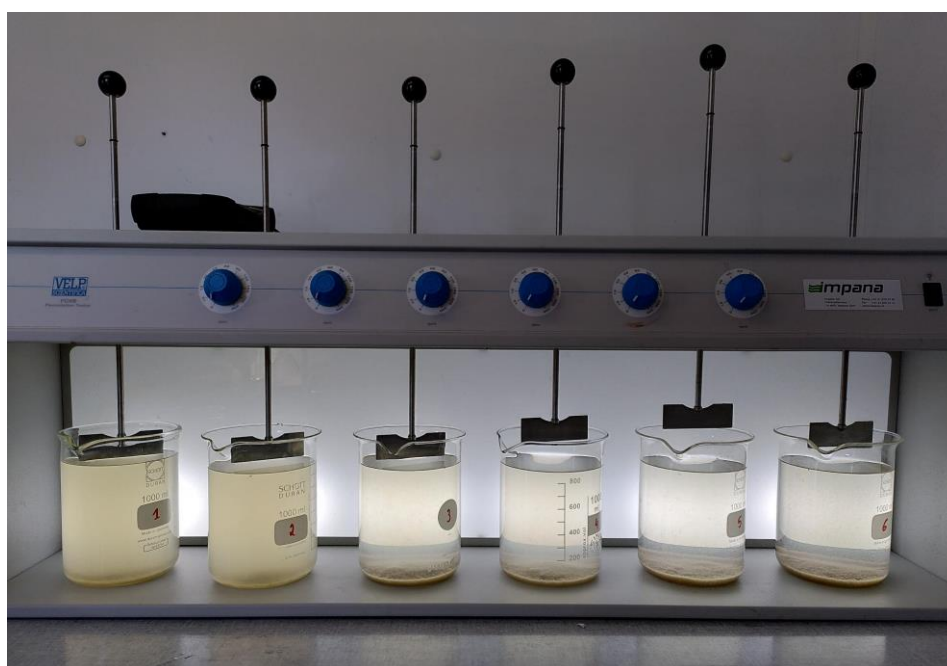


Figure 7 - Flocculator used for the jar tests

2.4 Additional measurements

Note that in addition to the sludge samples collected from the microsieve (as described in section 2.1), a few sludge samples⁵ were also taken from the primary settler situated in the experimental hall of Eawag (HRT = 1h). These additional measurements allow to compare

⁵ Once per day, between 04/05/2022 and 06/05/2022.

primary settling and microsieving (with and without chemical-enhancement) in terms of sludge properties.

Moreover, Table 6 shows that previous works with microsieves carried out with the collaboration of Eawag allowed to collect and analyse sludge samples produced by microsieves. Measurements marked with a star sign (*) correspond to the ones that were carried out during this work (even though sampling was done before the start of this work). All results regarding sludge properties (obtained from this work and previous works) will be discussed together.

Table 6 – Measurements of sludge properties related to other works carried out with the collaboration of Eawag

Microsieve type and mesh size	Location	VS/TS	Cellulose	BMP
DS Nordic Dynadrum 100 µm	Münchwilen, Switzerland	x*	x*	
RBF Nordic Sobyte 300 µm	Münchwilen, Switzerland	x*	x*	
RBF Nordic Sobyte 300 µm	Cully, Switzerland	x		x
RBF Nordic Sobyte 300 µm + DS Nordic Dynadrum 30 µm	Täuffelen, Switzerland	x	x	x
DS Huber Liquid 200 µm	Sihltal, Switzerland	x		x

2.5 Linking capture performances and sludge properties

When considering the overall energy balance of a WWTP, knowing the BMP of the sludge (which is expressed in Nml CH₄/g VS) is not enough to compute the amount of methane in terms of Nml CH₄/l of wastewater. Obviously, capture performances need to be taken into account to determine how much VS/l of wastewater ends up in the sludge. However, as the mass of VS in the sludge per liter of wastewater was not directly measured, one must assume that the mass of VSS removed from wastewater is equal to the mass of VS that is found in the sludge (in order words that, in the sludge, VS can be considered equal to VSS). A BMP value expressed in Nml CH₄/l WW) can therefore be estimated using the following equation:

$$\begin{aligned}
 BMP \left[\frac{Nml \text{ CH}_4}{l \text{ WW}} \right] &= BMP \left[\frac{Nml \text{ CH}_4}{g \text{ VS}} \right] * \text{Captured VS} \left[\frac{g \text{ VS}}{l \text{ WW}} \right] \\
 &= BMP \left[\frac{Nml \text{ CH}_4}{g \text{ VS}} \right] * (\text{Influent VSS} - \text{Effluent VSS}) \left[\frac{g \text{ VSS}}{l \text{ WW}} \right] \\
 &= BMP \left[\frac{Nml \text{ CH}_4}{g \text{ VS}} \right] * \text{Influent VSS} \left[\frac{g \text{ VSS}}{l \text{ WW}} \right] * \text{VSS removal} \left[\frac{g \text{ VSS}}{g \text{ VSS}} \right]
 \end{aligned}$$

The same approach can be applied to cellulose, to estimate how much cellulose is captured in the sludge per liter of wastewater:

$$\begin{aligned}
 \text{Captured cellulose} \left[\frac{g}{l \text{ WW}} \right] &= \text{Cellulose content} \left[\frac{g}{g \text{ VS}} \right] * \text{Captured VS} \left[\frac{g \text{ VS}}{l \text{ WW}} \right] \\
 &= \text{Cellulose content} \left[\frac{g}{g \text{ VS}} \right] * (\text{Influent VSS} - \text{Effluent VSS}) \left[\frac{g \text{ VSS}}{l \text{ WW}} \right] \\
 &= \text{Cellulose content} \left[\frac{g}{g \text{ VS}} \right] * \text{Influent VSS} \left[\frac{g \text{ VSS}}{l \text{ WW}} \right] * \text{VSS removal} \left[\frac{g \text{ VSS}}{g \text{ VSS}} \right]
 \end{aligned}$$

Furthermore, knowing the cellulose content in the influent (or using the value of 33% TSS measured by Ahmed et al. [16]), one can estimate the cellulose capture rate:

$$\begin{aligned}
 \text{Cellulose capture rate} [\%] &= \frac{\text{Captured cellulose} \left[\frac{g}{l \text{ WW}} \right]}{\text{Influent cellulose} \left[\frac{g}{l \text{ WW}} \right]} * 100 \\
 &= \frac{\text{Captured cellulose} \left[\frac{g}{l \text{ WW}} \right]}{\text{Influent cellulose content} \left[\frac{g}{g \text{ TSS}} \right] * \text{Influent TSS} \left[\frac{g \text{ TSS}}{l \text{ WW}} \right]} * 100 \\
 &\simeq \frac{\text{Captured cellulose} \left[\frac{g}{l \text{ WW}} \right]}{0.33 \left[\frac{g}{g \text{ TSS}} \right] * \text{Influent TSS} \left[\frac{g \text{ TSS}}{l \text{ WW}} \right]} * 100
 \end{aligned}$$

3 Results

3.1 Capture performances

The microsieve capture performances associated with each tested condition are summarized in Figure 8 with boxplots of the TSS, VSS, and COD removal rates according to the type of chemicals and their concentrations. The exact median removal rates, interquartile ranges (IQR), and number of data points associated with each condition can be found in Appendix B.

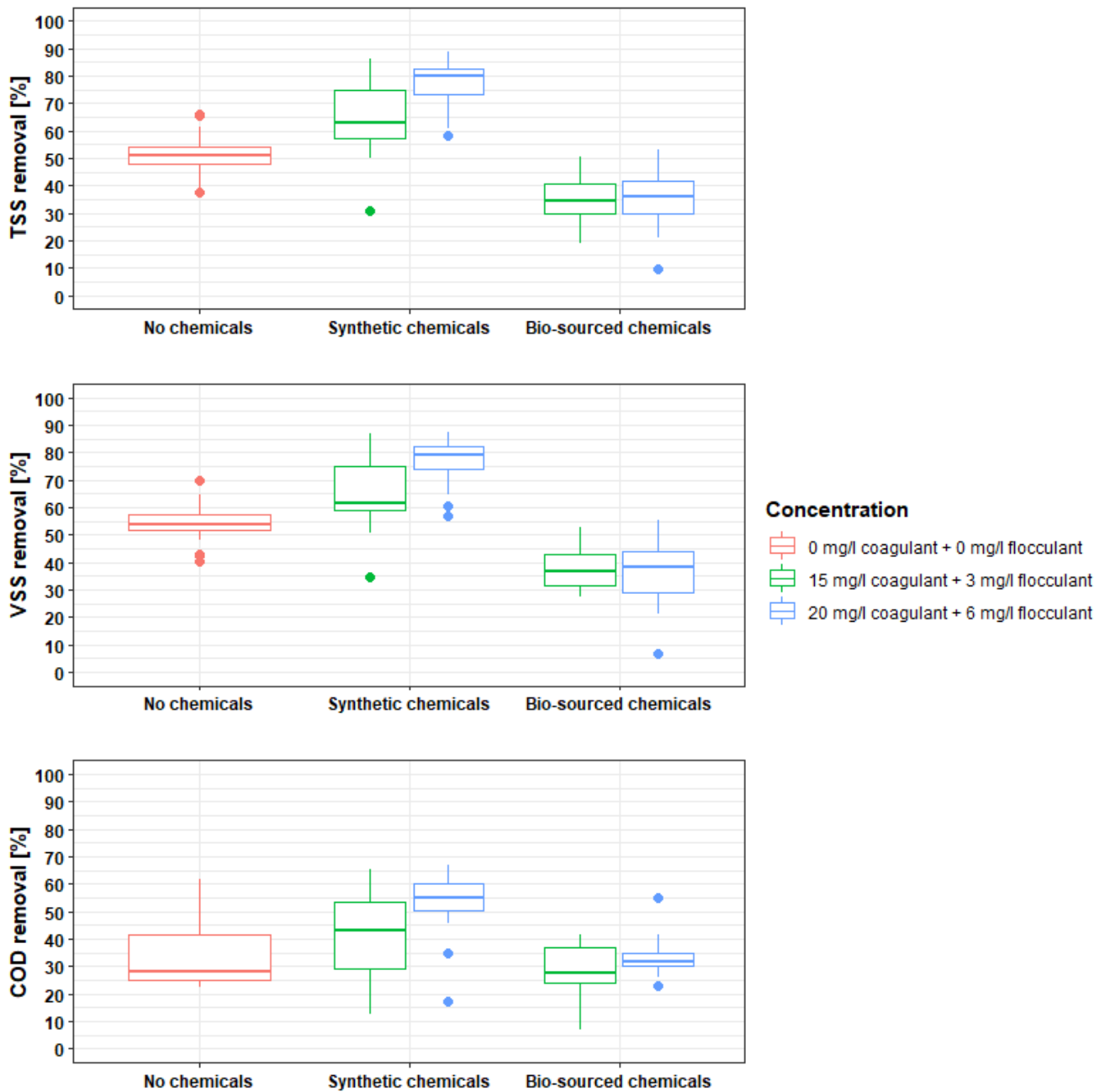


Figure 8 – Boxplots of the TSS, VSS, and COD removal rates according to the type of chemicals and their concentrations

Without chemicals, median removal rates for TSS and VSS are around 50% while for COD the median removal rate reaches 30%. With the addition of synthetic chemicals, median removal rates for TSS and VSS increase to around 60% with the use of 15 mg/l of coagulant and 3 mg/l of flocculant and reach 80% with 20 mg/l of coagulant and 6 mg/l of flocculant. Regarding COD, median removal rates reach respectively 45 and 55%. These results clearly show that the addition of synthetic chemicals leads to increased capture performances of the microsieve.

Regarding bio-sourced chemicals, the results are different than what was expected. First, the increase in chemical concentrations does not lead to significant increases of the median removal rates as observed with synthetic chemicals. Even though the median removal rates are slightly higher with 20 mg/l of coagulant and 6 mg/l of flocculant than with 15 mg/l of coagulant and 3 mg/l of flocculant, in both cases the median removal rates remain around 35% for TSS and VSS and around 30% for COD. More surprisingly, one can see that these values are even lower than the removal rates obtained with no addition of chemicals. This clearly indicates that the desired effect of coagulant and flocculant addition did not occur. This issue is further discussed at the end of this section.

Plotting the removal rates according to the influent TSS concentration (see Figure 9) provides more insights on the performances of the system. Indeed, looking at the capture performances of the microsieve with no addition of chemicals, one can see that TSS and VSS removal rates tend to increase with increasing influent TSS concentration. With the addition of synthetic chemicals, this trend is even more pronounced showing that the gain in removal performances tends to increase with increasing influent TSS concentration. In addition, one can notice that the difference of 20% in TSS and VSS removal rates observed between the two chemical dosages is systematic across the range of influent TSS concentrations. As shown in Appendix C, it is important to note that while a strong linear correlation ($R^2 = 0.985$) was observed between VSS and TSS removal rates, the linear correlation between COD and TSS removal rates is weaker ($R^2 = 0.311$). This means that, knowing the influent TSS concentration, one can predict well both TSS and VSS removal rates but cannot predict well the COD removal rate. However, looking closely at the correlation between COD and TSS removal rates, a few points with high COD removal rates but low TSS removal rates or low COD removal rates but high TSS removal rates lie far from the other points associated with the same condition. By removing these points (arbitrarily), the R^2 value increases from 0.311 to 0.719 meaning that for this selection of points the influent TSS concentration gives a better estimate of the COD removal rate that can be expected. For the purpose of clarity regarding the messages that can be drawn from this work, COD removal trendlines in Figure 9 also exclude these 'off trend' points (all

data points are however still displayed). As a result, it appears that, similarly to TSS and VSS removal rates, COD removal rates tend to increase with increasing influent TSS concentrations and that this effect is even stronger with the addition of synthetic chemicals. However, one must remain cautious with the interpretation of these results. First, because the number of COD measurements remains limited. Also because, as just described, some points were excluded from the trendlines. And finally, because the distribution of points across the range of influent TSS concentrations differs from one condition to another (in the case of synthetic chemicals, one can see that the trendline for 20 mg/l of coagulant + 6 mg/l of flocculant is influenced by two points with influent TSS concentration higher than 300 mg/l while the trendline for 15 mg/l of coagulant + 3 mg/l of flocculant is not).

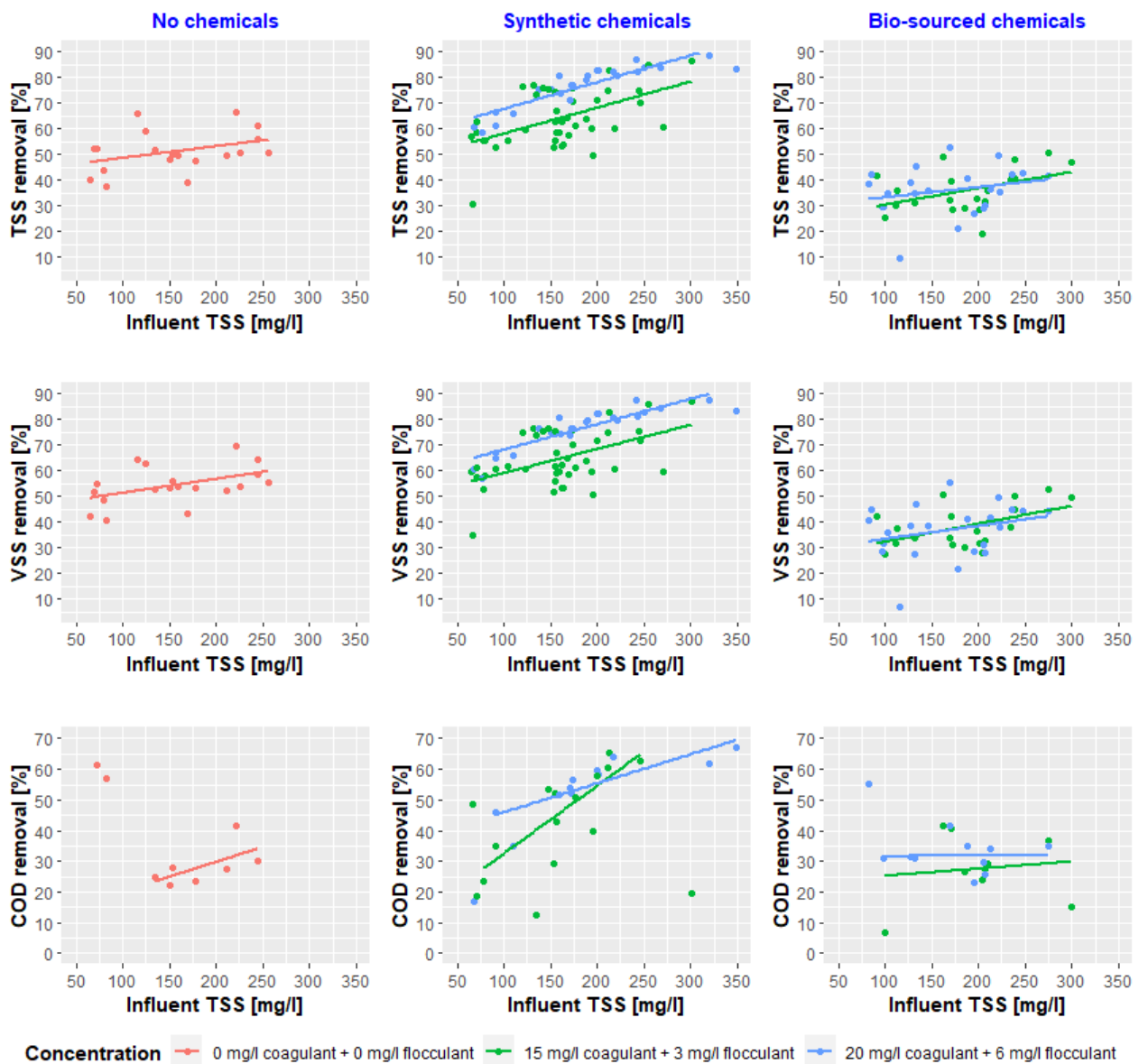


Figure 9 - Capture performances according to influent TSS concentration

The poor capture performances obtained with bio-sourced chemicals called for further investigations. First, even if it is mentioned in section 2.1 that jar tests were performed with the products before proceeding with the tests with the microsieve, it is important to note that an additional series of jar tests was performed because the bio-sourced cationic powder used during this work is from another manufacturer than the one used in the preliminary tests. This change of product is due to the fact that the original supplier stopped the production of the powder. A new series of jar tests was therefore performed to check that this new combination of coagulant and flocculant effectively leads to increased turbidity, TSS, and VSS removal rates. The detailed results of this test are presented in Appendix D and are summarized in Table 7. It is important to remember that sieving and settling are two different physical processes for particle removal. One can therefore not expect the removal rates to be the same with a jar test and with the microsieve. However, the jar test shows whether the use of coagulant and flocculant effectively results in the formation of flocs that can either settle in the jar or be retained on the sieve mesh. In the case of the bio-sourced chemicals, the jar test results show that the addition of chemicals indeed leads to the formation of flocs and therefore to a significant increase in the removal of turbidity, TSS, and VSS (up to 90%). It can therefore be excluded that the change of cationic powder is the cause of the poor capture performances obtained with the microsieve.

Table 7 – Removal rates obtained during the jar tests performed with the bio-sourced chemicals

Condition	Turbidity	TSS	VSS
No Chem	45%	70%	70%
Bio 15+3	84%	85%	85%
Bio 20+6	90%	88%	89%
<i>Influent characteristics</i>	<i>99 NTU</i>	<i>225 mg/l</i>	<i>201 mg/l</i>

Another possible cause of poor capture performances would be a malfunction of the microsieve or of another component of the experimental setup. Even if this cause cannot be fully excluded, no particular sign of malfunction was detected during the tests performed with the bio-sourced chemicals. Moreover, the microsieve was used again after these tests to perform additional measurements with the use of 15 mg/l of synthetic coagulant and 3 mg/l of flocculant (see Table 4) and the microsieve capture performances were similar to what was obtained earlier (see Appendix E).

Therefore, the most probable cause of the poor performances obtained with the bio-sourced chemicals appears to be that the flocculation process could not occur properly. This hypothesis

seems credible also because flocs could not really be observed at the surface of the flocculation tank during the tests, whereas it was the case with the synthetic products. The formation of flocs may have been impaired because of the conditions in the flocculation tank: too short hydraulic residence time or too high mixing intensity. It is also possible that the strength of the flocs was too weak to withstand the flow conditions in the system from the flocculation tank to the microsieve mesh (which is an issue that was previously reported in the scientific literature [25]). As the experimental setup was the same during all tests (including with the synthetic chemicals), it appears that the conditions under which the flocculation process yields satisfactory results differ depending on the products used.

3.2 Sludge properties

This section presents successively the results of VS-TS ratio, BMP, and cellulose content obtained for each condition⁶. However, note that the following figures also include additional results. Part of them corresponds to results obtained from other works carried out with the collaboration of Eawag (as described in section 2.4). The other share corresponds to results that can be found in the scientific literature. The figures therefore give an overview of the knowledge that exists regarding the properties of sludges obtained with microsieves in comparison with primary settlers. Note that the labels correspond to the type of microsieve used (DS or RBF), its manufacturer, and the mesh size (if known). In this section, the focus remains on the results obtained for each condition tested with the pilot-scale drum screen located in Eawag experimental hall. Section 4.2 includes a discussion of all results together.

⁶ The exact average numbers with associated standard deviation and number of data points can be found in Appendix F.

3.2.1 VS-TS ratio

Looking at section A of Figure 10, it can be observed that, while the sludge from the microsieve (without chemical-enhancement) and the primary settler have a similar VS-TS ratio (~80%), the addition of synthetic chemicals results in a decrease of VS-TS ratio with increasing dosage (down to ~70%). This shows that the chemicals tend to increase the share of inorganic particles captured in the sludge. On the other hand, depending on the dosage, the use of bio-sourced chemicals results in no or lower decrease of VS-TS ratio, which is consistent with the fact that their addition did not lead to increased capture performances.

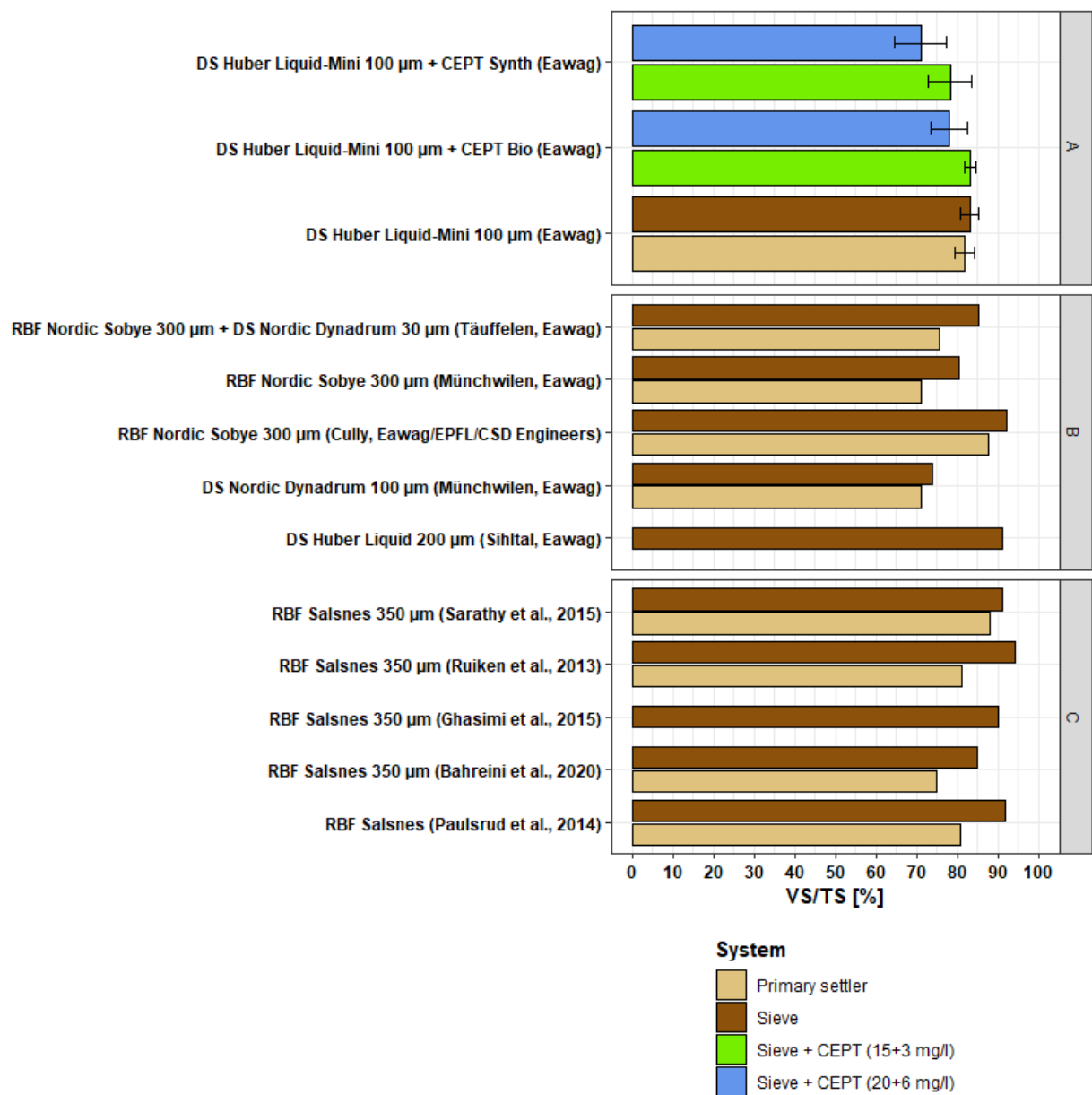


Figure 10 - Sludge VS-TS ratio according to the type of primary treatment

3.2.2 BMP

Regarding BMP measurements, due to time and organizational constraints, it was unfortunately not possible to carry out a test with the sludge from the primary settler. Moreover, given the poor capture performances obtained with the bio-sourced chemicals, it was chosen not to measure BMP for these samples. Therefore, the results only allow to show the effect of the synthetic chemicals. It appears that, compared to microsieving without chemical-enhancement, the use of synthetic chemicals results in decreasing BMP with increasing dosage (from ~350 to 270 Nml CH₄/g VS) (see section A of Figure 11). This means that the mix of organic particles captured with chemical-enhancement tends to be less interesting in terms of BMP.

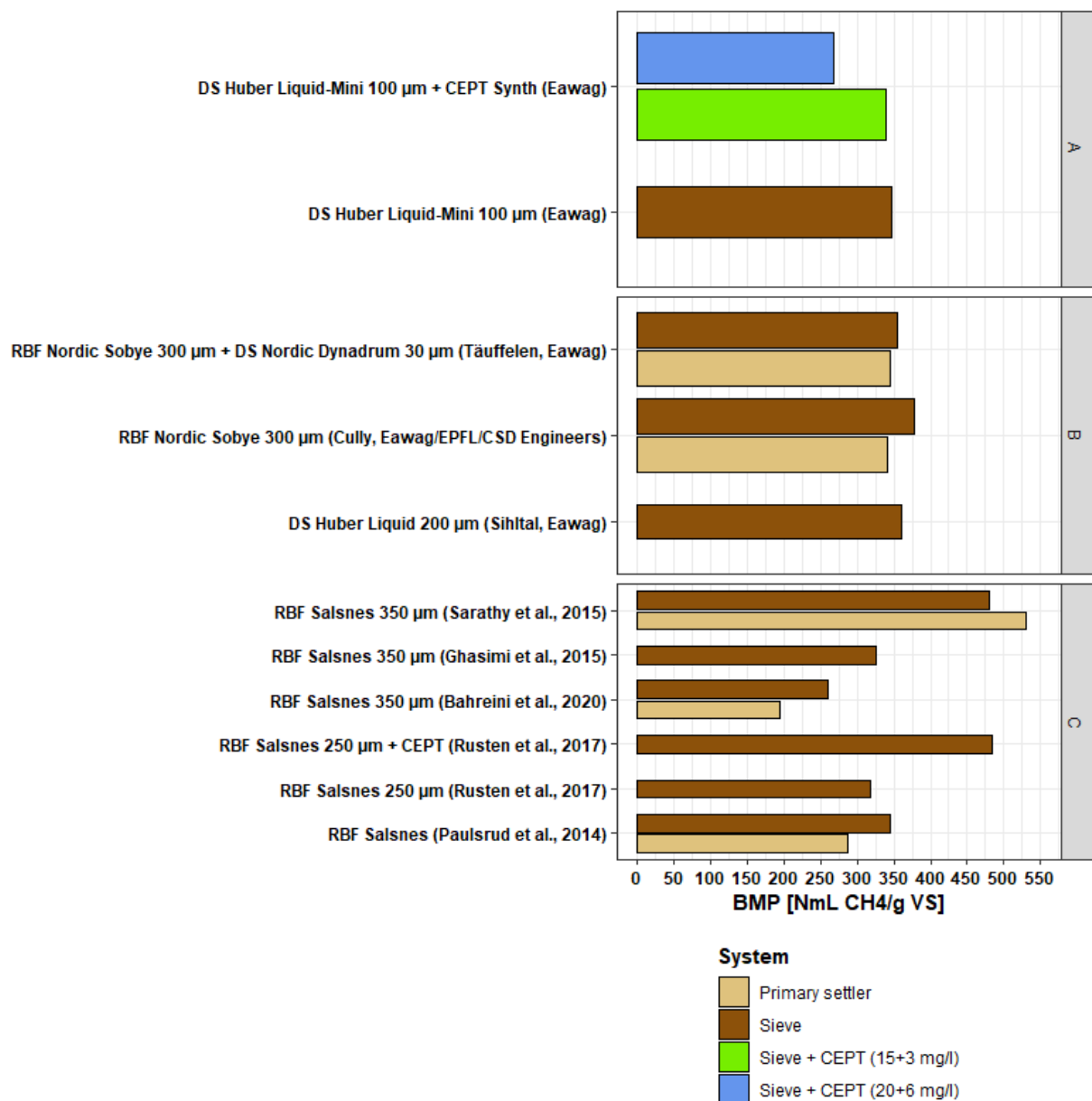


Figure 11 - Sludge BMP according to the type of primary treatment

3.2.3 Cellulose content

Figure 12 provides cellulose content data expressed in terms of TS. It can be observed that, compared to the primary settler, the cellulose content is higher in the sludge from the microsieve (from ~35 to 45% TS). This shows that microsieving produces a sludge that is richer in cellulose. However, the addition of synthetic chemicals reduces this effect as cellulose content decreases with increasing chemical dosage (down to ~30% TS).

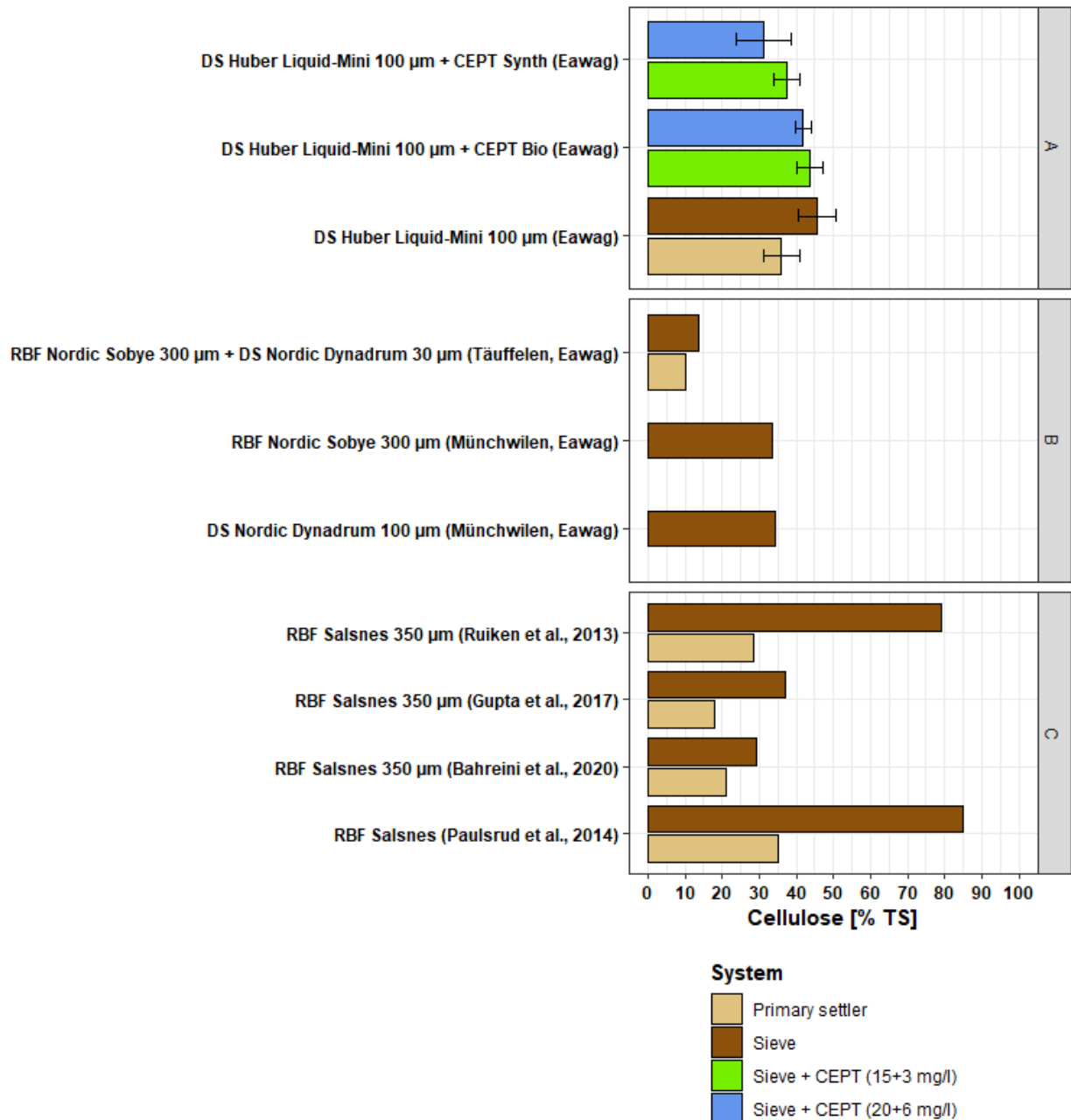


Figure 12 - Sludge cellulose content (expressed in %TS) according to the type of primary treatment

As cellulose is an organic compound, it is also interesting to look at the cellulose content in terms of VS (see Figure 13). As a result, one can see that, compared to the primary settler, cellulose represents a higher share of the organics in the sludge from the microsieve. On the other hand, the addition of synthetic chemicals leads to a reduction of the share of cellulose in the sludge organics with increasing dosage. Linking these results with the changes in VS-TS ratio (section 3.2.1), it appears that, compared to the primary settler, the microsieve produces a sludge with as much organics but the share of cellulose is higher while the addition of synthetic chemicals reduces the amount of organics as well as their content in cellulose.

Regarding the effect of the bio-sourced chemicals, it can be noted, in terms of both TS and VS, that the cellulose content remains similar to the results obtained without chemical-enhancement, which is again consistent with the fact that their use did not lead to increased capture performances.

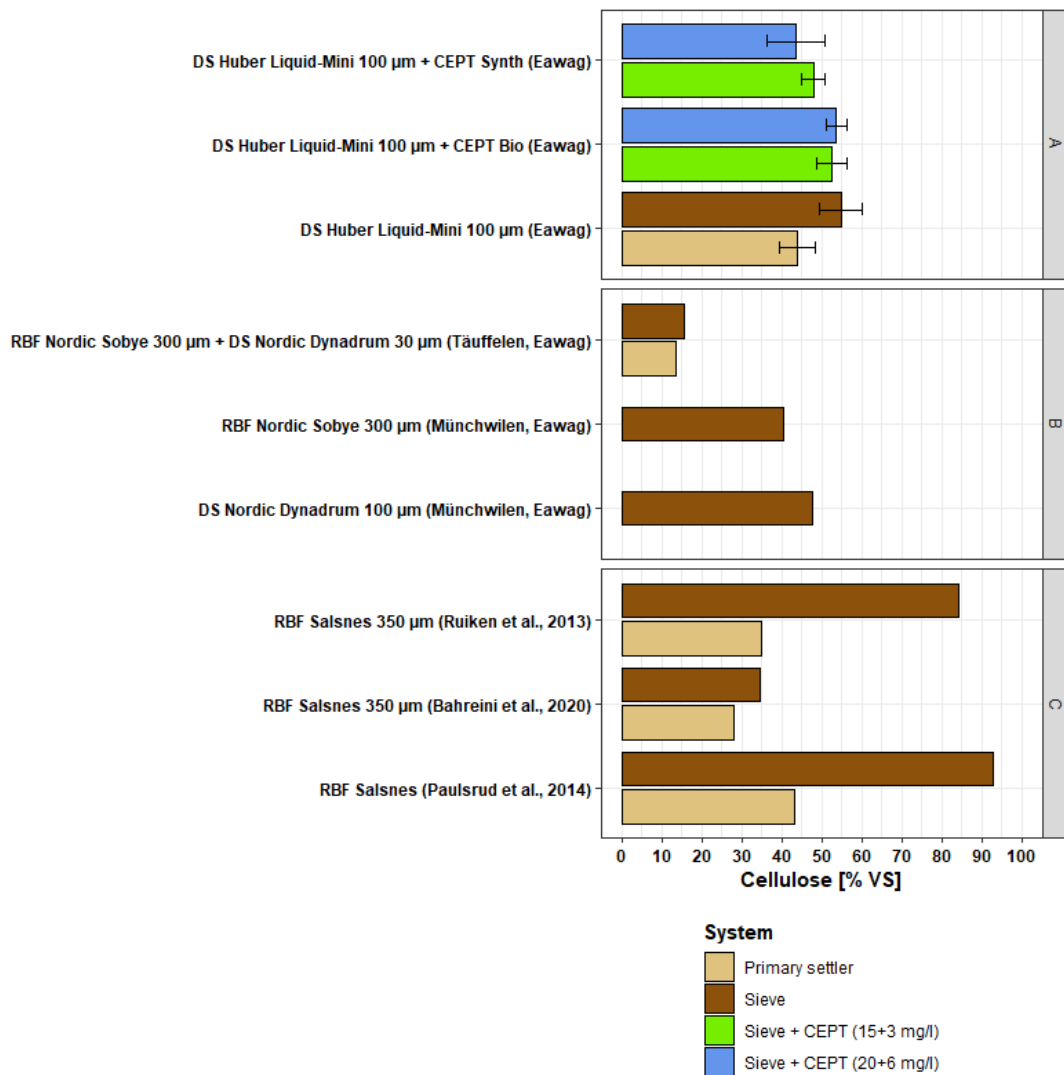


Figure 13 - Sludge cellulose content (expressed in % VS) according to the type of primary treatment

4 Discussion

4.1 Capture performances

As shown in section 3.1, the use of synthetic chemicals resulted in a clear effect on the microsieve capture performances (from ~50 to 80% for TSS and VSS and from ~30 to 55% for COD). While capture performances without chemical-enhancement (~50% for TSS) are in line with the values found in the literature (between 40 and 60% for TSS⁷), the removal rates obtained with the addition of synthetic chemicals (up to 80% for TSS) correspond to the low end of the range found in the literature (between 80 and 90% for TSS⁷). It is however worth reminding that the results also show that capture performances tend to increase with increasing influent TSS concentration, which means that variations in removal rates are to be expected with changes in location and time. Optimisation of the dosing is therefore key when implementing chemically-enhanced microsieving if one seeks to achieve specific average removal rates. Furthermore, working on the development of a system that would allow real-time dosing adjustments depending on the influent TSS concentration would be an interesting way to reach increased average removal rates while minimizing chemical use.

As the increased capture performances expected from chemical-enhancement rely on the formation of flocs upstream of the sieving unit, it appears essential to ensure that the conditions in the system (hydraulic residence time, mixing, pipe flow) allow flocs to form and persist until they reach the microsieve mesh. This factor appears to be, at least partially, the cause of the poor performances obtained with the bio-sourced products. Even if there is no reason to believe that the products tested are inefficient for the chemical-enhancement of wastewater microsieving, this work cannot prove otherwise. Further tests would be necessary to understand under which conditions they could be used for wastewater microsieving applications. More generally, a better understanding of the factors influencing the formation and persistence of flocs in the context of microsieving, including product type, would probably allow to improve capture performances and/or optimize chemical use.

4.2 Sludge properties

As already mentioned, the figures regarding sludge properties (section 3.2) include data from previous works carried out with the collaboration of Eawag and from the scientific literature and therefore provide a basis for comparison with the results obtained during this work. Starting with VS-TS ratio, while the results from this work showed similar ratios between the drum-screen (without chemical-enhancement) and the primary settler, the additional data (mostly

⁷ See Table 1

obtained with RBFs) tends to show higher VS-TS ratios for microsieving compared to settling (respectively ~85 and 80% on average). It therefore appears that microsieves (especially RBFs) usually produce sludge with higher VS content than primary settlers. Regarding BMP values, it is important to recognize that variations in the results are high (especially for primary settlers where values range from ~200 to more than 500 Nml CH₄/g VS). However, it can be observed that BMP tends to be higher for microsieves than for primary settlers (with median values respectively ~345 and 315 Nml CH₄/g VS). Finally, regarding cellulose content, variations are also high (with values ranging from ~10 to 85% TS) but the results always show higher cellulose content for microsieves compared to primary settlers.

To summarize, it appears that microsieving (with no chemical-enhancement) produces sludge with (equal or) higher VS content, higher BMP, and higher cellulose content than settling. While increasing chemical dosing (using synthetic chemicals) reduces these effects and may even result in lower values than those obtained with primary settlers.

4.3 Linking capture performances and sludge properties

As described in section 2.5, sludge properties and capture performances need to be considered together in order to estimate the impact on the amount of methane or cellulose that can be recovered from a WWTP due to changes in the primary treatment. Note that the detailed calculations behind the numbers shown in the following figures can be found in Appendix G.

4.3.1 BMP

Even though a decrease in BMP was observed with increasing chemical dosage (section 3.2.2), Figure 14 shows that, per liter of wastewater treated, the microsieve yields a higher BMP than the primary settler⁸ and the addition of synthetic chemicals results in even higher BMP values with increasing dosage. This means that the increased capture of solids obtained with chemical-enhancement more than compensates the decrease in BMP (when expressed in Nml CH₄/g VS).

4.3.2 Cellulose capture

Figure 15 shows that, compared to the primary settler, cellulose capture per liter of wastewater is higher with the microsieve (from ~60 to 70%). Moreover, the addition of synthetic chemicals results in even higher capture rates (up to ~90%). Similar to BMP, this means that the increased capture performances obtained with chemical-enhancement more than compensate the decrease of sludge cellulose content.

⁸ Note that as no BMP test was carried out with the sludge from the primary settler, the value taken to provide these estimations is the median value of the results obtained from the literature and the other works carried out with the collaboration of Eawag (315 Nml CH₄/g VS, see section 4.2).

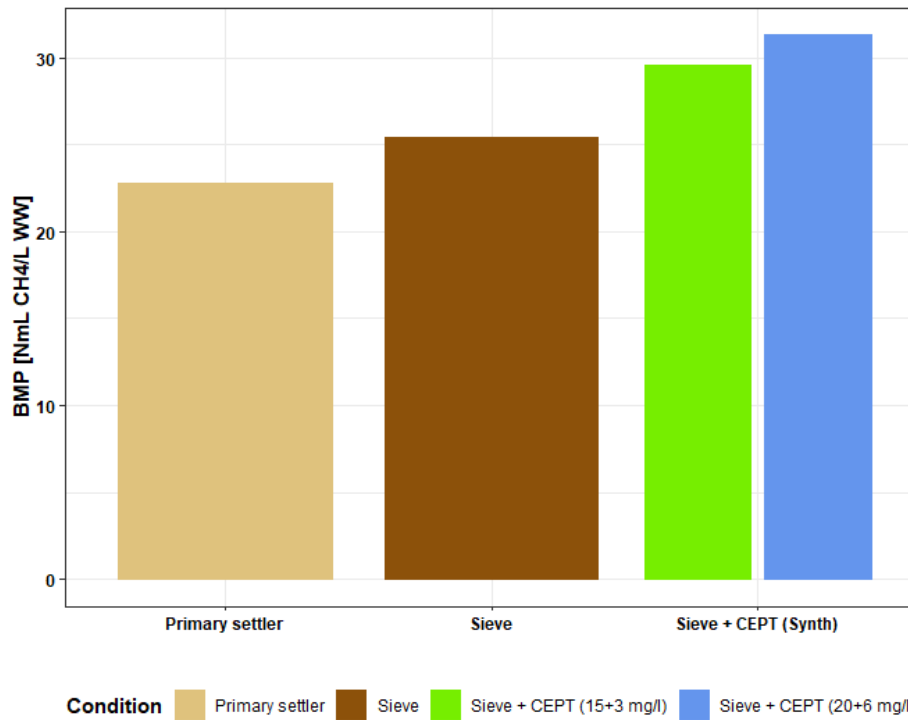


Figure 14 – Estimated sludge BMP (expressed per liter of wastewater) depending on the type of primary treatment

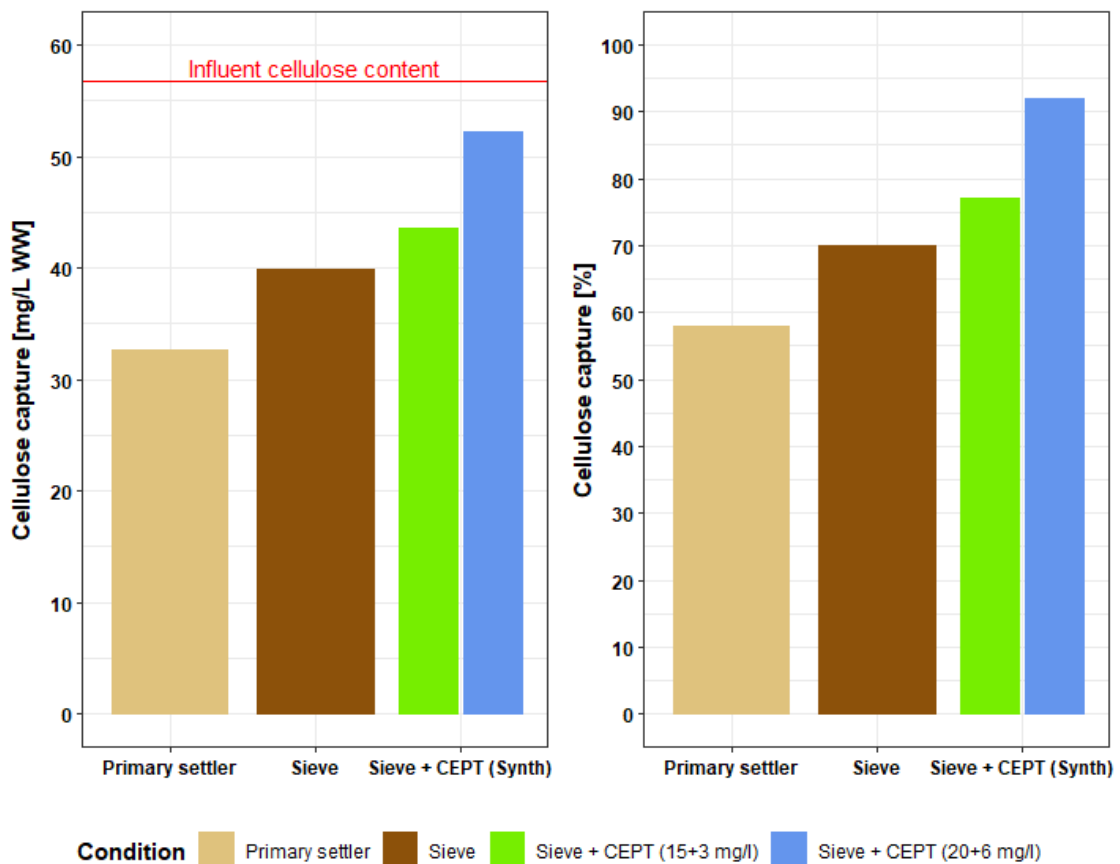


Figure 15 - Estimated amount of cellulose captured in the sludge per liter of wastewater depending on the type of primary treatment

4.3.3 Overall balance

Besides these considerations regarding methane and cellulose, it is important to remember that the other benefit brought by chemical-enhancement is the reduction of the amounts of TSS, VSS, and COD in the effluent, which is then transferred to the biological treatment. Figure 16 shows the changes, per liter of wastewater, brought by microsieving (with and without addition of synthetic chemicals) in terms of the amounts of TSS, VSS, and COD that are transferred to the biological treatment and in terms of BMP and recovered cellulose compared to settling. Note that, as in these estimations the performances of the microsieve (without chemical-enhancement) and those of the primary settler were considered equal for TSS, VSS, and COD removal, there is no difference between the two technologies for these parameters. However, with the addition of synthetic chemicals, effluent TSS and VSS are reduced by up to ~60% while effluent COD is reduced by up to ~35%. Regarding BMP, microsieving (without chemical-enhancement) yields an increase of ~10% while with the addition of synthetic chemicals this increase can go up to ~35%. In terms of cellulose capture, the use of the microsieve results in an increase of ~20% without chemical-enhancement and the increase can reach ~60% with the addition of synthetic chemicals. Carrying out these calculations therefore clearly demonstrates the potential offered by microsieving, especially chemically-enhanced microsieving, both in terms of the reduction of the loads transferred to the biological treatment and in terms of increased methane production or cellulose recovery.

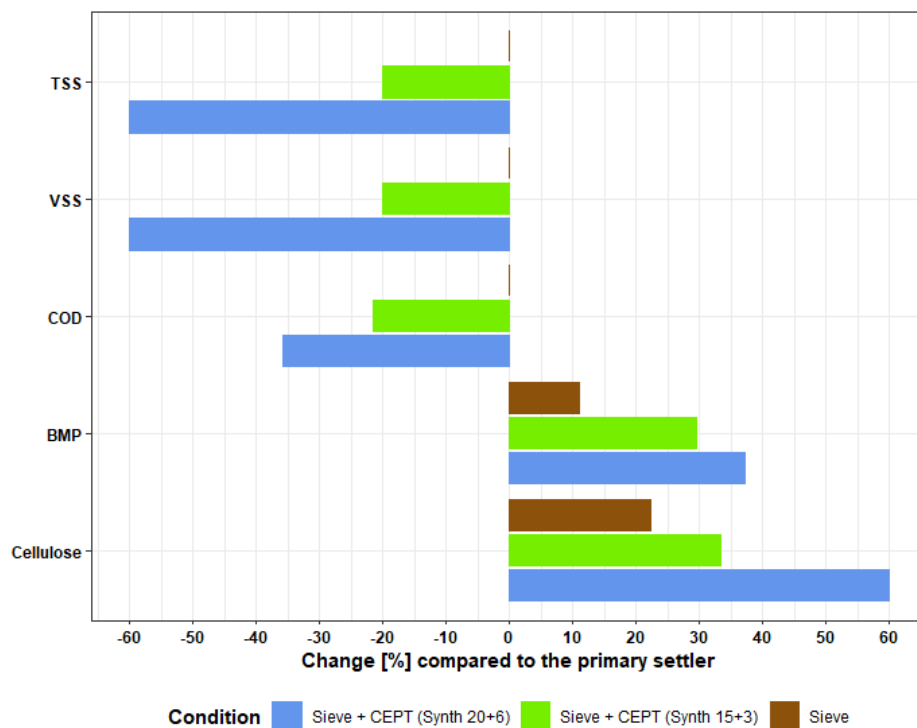


Figure 16 - Estimated changes in terms of effluent TSS, VSS, and COD as well as sludge BMP and cellulose capture per liter of wastewater depending on the type of primary treatment (with primary settling as a reference)

However, it is important to remain aware of the limits associated with these results. First, since the amount of sludge produced per liter of wastewater had to be estimated (section 2.5), values of BMP and cellulose capture per liter of wastewater also remain estimations. Moreover, one must remember that during this work the microsieve was never connected to any kind of biological or sludge treatment. This means that this work does not allow to study the full implications that changes in the primary treatment have on a complete wastewater treatment scheme. For instance, the estimations of changes in biogas production are based on BMP measurements. But it is important to keep in mind that BMP is a measure of potential methane production based on a batch test. In a real WWTP, anaerobic reactors are continuously fed with sludge and methane production does not necessarily correspond to its potential value. Furthermore, as only one BMP measurement could be carried out per condition tested with the microsieve, additional tests would be necessary to confirm the current results. Ideally, further experiments should therefore be performed on complete wastewater treatment trains such that changes in the primary treatment could be studied together with their effect on the other treatment steps.

Last but not least, if this work suggests that chemical-enhancement allows to reduce the loads transferred to the biological treatment while increasing methane production or cellulose recovery, the use of chemicals is not free of impacts (in terms of energy required for their production, associated GHG emissions, and overall environmental impact). Optimizing their use is therefore key to minimize the additional impact that they bring while maximizing the benefits associated with increased capture performances of the primary treatment.

5 Conclusion

The goal of this work was to bring more knowledge regarding the use of microsieves, specifically drum screens, for the primary treatment of wastewater in the context where solutions need to be developed to reduce the environmental impact of WWTPs, notably their use of energy.

On the one hand, this work focused on the extent to which solids can be captured using microsieves (with and without chemical-enhancement). The results showed that chemical-enhancement (using synthetic polymers) significantly increases the capture performances of the microsieve. Indeed, while microsieving without chemical-enhancement resulted in removal rates of 50% for TSS and VSS and 30% for COD, removal rates of 80% for TSS and VSS and 55% for COD were obtained with chemically-enhanced microsieving.

On the other hand, the effect of microsieving and chemical-enhancement on sludge properties was analysed. Results showed that, compared to primary settling, microsieving (without chemical-enhancement) produces sludge with (equal or) higher VS content, higher BMP, and higher cellulose content. However, increasing chemical dosing (using synthetic polymers) reduces these effects and may even result in lower values than those obtained with primary settlers.

Furthermore, linking capture performances with sludge properties allowed to estimate that, compared to primary settling, microsieving without and with chemical-enhancement could lead to increases in methane production of respectively 10% and 35% or in cellulose recovery of respectively 20% and 60%. At the same time, chemical-enhancement could reduce by 60% the amounts of TSS and VSS transferred to the biological treatment and by 35% the amount of COD. This shows that working on the improvement of wastewater primary treatment has a great potential to improve the overall performance of WWTPs in terms of energy balance and resource recovery. However, these results remain estimations and further experiments on complete wastewater treatment trains should be performed to confirm these findings. Additionally, it is important to keep in mind that the environmental impact and energy use associated with the production and use of the chemicals still need to be taken into account. Optimizing their use would therefore be key to minimize the additional impact that they bring while maximizing the benefits associated with increased capture performances of the primary treatment. Last but not least, it must be mentioned that, while this work intended to compare bio-sourced and synthetic chemical products, it did not make sense to carry out the estimations of methane production and cellulose recovery for the bio-sourced products considering the poor capture performances that were obtained so far.

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Appendices

A. Results obtained when using α -cellulose as a standard to test the quantification method of cellulose in sewage sludges

Sample	Cellulose recovery
1	90.4%
2	89.7%
3	88.7%
4	85.3%
5	85.6%
6	86.8%
Mean	87.7%
Standard deviation	2.2%

B. Removal rates associated with each condition tested

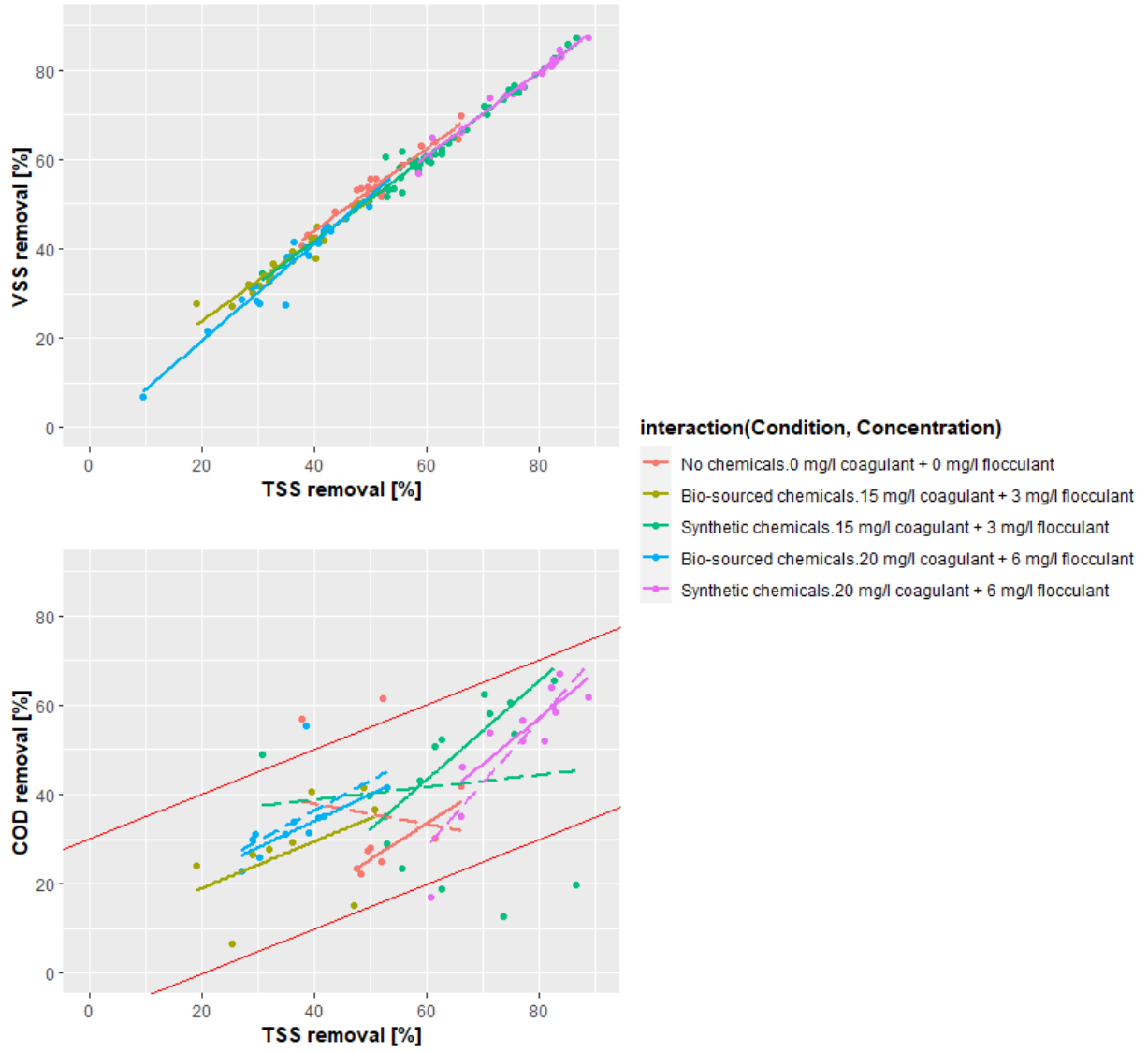
a. Median values \pm IQR/2 and number of data points

Condition	Removal rates [%]		
	TSS	VSS	COD
No Chem	50.9 \pm 3.02 (n = 19)	53.8 \pm 2.69 (n = 19)	28.1 \pm 8.38 (n = 9)
Synth 15+3	62.8 \pm 8.75 (n = 41)	61.6 \pm 8.00 (n = 41)	43.1 \pm 12.2 (n = 17)
Synth 20+6	79.9 \pm 4.67 (n = 24)	79.2 \pm 3.98 (n = 24)	55.2 \pm 4.84 (n = 12)
Bio 15+3	34.4 \pm 5.41 (n = 20)	36.9 \pm 5.62 (n = 20)	27.6 \pm 6.33 (n = 9)
Bio 20+6	36.2 \pm 5.99 (n = 22)	38.4 \pm 7.44 (n = 22)	31.5 \pm 2.24 (n = 11)


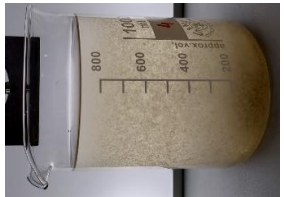


b. Average values with standard deviation and number of data points

Condition	Removal rates [%]		
	TSS	VSS	COD
No Chem	51.2 \pm 8.03 (n = 19)	54.3 \pm 7.61 (n = 19)	35.2 \pm 14.8 (n = 9)
Synth 15+3	64.4 \pm 10.7 (n = 41)	64.8 \pm 10.7 (n = 41)	42.1 \pm 16.6 (n = 17)
Synth 20+6	76.7 \pm 8.55 (n = 24)	76.6 \pm 8.14 (n = 24)	51.9 \pm 13.9 (n = 12)
Bio 15+3	35.9 \pm 8.56 (n = 20)	38.2 \pm 7.97 (n = 20)	27.6 \pm 11.5 (n = 9)
Bio 20+6	35.9 \pm 9.58 (n = 22)	36.7 \pm 10.7 (n = 22)	33.9 \pm 8.60 (n = 11)

C. Correlation of VSS and COD removal rates with TSS removal rates

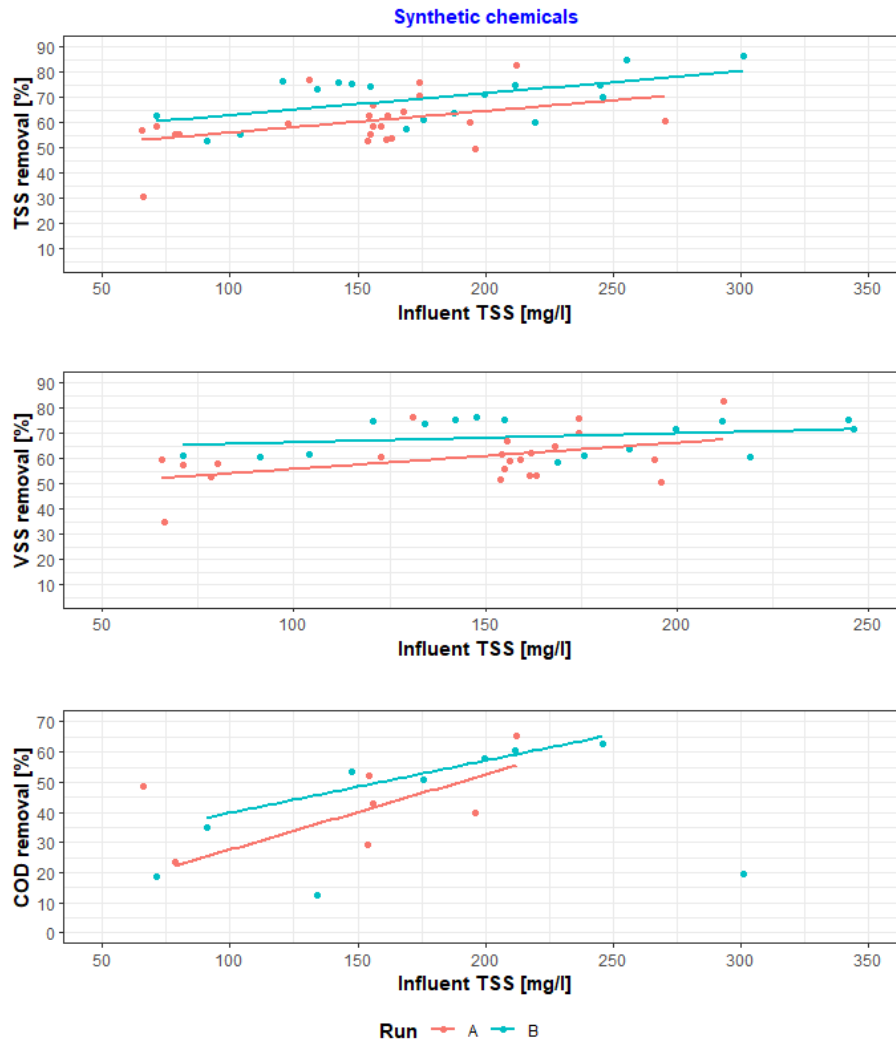


D. Jar tests performed with bio-sourced chemicals

Label	1	2	3	4	5	6	7	8
Condition	No Chem	No Chem	Bio 15+3	Bio 15+3	Bio 20+6	Bio 20+6	Influent	Influent
Before settling								
After settling								
Turbidity [NTU]	53.6	55.2	14.7	17.2	9.3	9.92	100	98.2
Mean turbidity	54.4	54.4	15.95	15.95	9.61	9.61	99.1	99.1
Turbidity removal [%]	45.1	45.1	83.9	83.9	90.3	90.3	-	-
TSS [mg/l]	70.4	65.2	33.6	36.4	22	30.8	228.8	220.8
Mean TSS	67.8	67.8	35	35	26.4	26.4	224.8	224.8
TSS removal [%]	69.8	69.8	84.4	84.4	88.3	88.3	-	-
VSS [mg/l]	64.8	56	28.4	31.2	20.4	24.8	200.8	201.2
Mean VSS	60.4	60.4	29.8	29.8	22.6	22.6	201	201
VSS removal [%]	70.0	70.0	85.2	85.2	88.8	88.8	-	-

E. Capture performances of the microsieve with 15 mg/l of synthetic coagulant and 3 mg/l of synthetic flocculant

Note that ‘Run A’ corresponds to the test that was started on May 4th and ‘Run B’ to the one started on July 7th (see Table 4).



F. Average values of sludge properties with associated standard deviation and number of data points for each condition tested

Condition	VS-TS ratio [%]	Cellulose [% TS]	Cellulose [% VS]	BMP [Nml CH ₄ /g VS]
Primary settler	81.7 ± 2.38 (n = 3)	36.0 ± 4.71 (n = 3)	44.0 ± 4.49 (n = 3)	-
No Chem	83.0 ± 2.15 (n = 11)	45.6 ± 5.41 (n = 11)	54.8 ± 5.41 (n = 11)	347 (n = 1)
Synth 15+3	78.3 ± 5.36 (n = 8)	37.4 ± 2.94 (n = 8)	47.8 ± 2.94 (n = 8)	338 (n = 1)
Synth 20+6	71.0 ± 6.42 (n = 6)	31.2 ± 7.22 (n = 6)	43.6 ± 7.22 (n = 6)	268 (n = 1)
Bio 15+3	83.2 ± 1.42 (n = 6)	43.6 ± 3.76 (n = 6)	52.4 ± 3.76 (n = 6)	-
Bio 20+6	78.1 ± 4.47 (n = 6)	41.9 ± 2.52 (n = 6)	53.7 ± 2.52 (n = 6)	-

G. Estimations, per liter of wastewater, of changes in cellulose capture, BMP, and effluent loads depending on the type of primary treatment

Note that the equations to compute cellulose capture and BMP per liter of wastewater are described in section 2.5. Also, note that, in the table below, the numbers associated with ‘measured’ parameters were rounded for simplicity.

	Parameter	Unit	Primary treatment				Comment
			PS	DS	DS + CEPT (Synth. 15+3)	DS + CEPT (Synth. 20+6)	
Influent	TSS	mg	170	170	170	170	Average of all measurements carried out during this work Calculated [Ahmed et al., 2019] Calculated Measured Calculated Measured Calculated Measured, except for PS* Calculated Calculated Calculated
	VSS	mg	145	145	145	145	
	COD	mg	450	450	450	450	
	VSS/TSS	-	0.85	0.85	0.85	0.85	
	Cellulose	g/g TSS	0.33	0.33	0.33	0.33	
	Cellulose	mg	56.7	56.7	56.7	56.7	
	TSS removal	-	0.5	0.5	0.6	0.8	
	VSS removal	-	0.5	0.5	0.6	0.8	
	COD removal	-	0.3	0.3	0.45	0.55	
	TS	mg	90.6	90.6	108.8	165.7	
Sludge	VS	mg	72.5	72.5	87	116	Assumption that VS(sludge) = VSS(sludge) Measured Measured Calculated Measured, except for PS* Calculated Calculated
	VS/TS	-	0.8	0.8	0.8	0.7	
	Cellulose	g/g VS	0.45	0.55	0.5	0.45	
	Cellulose captured	mg	32.6	39.9	43.5	52.2	
	Cellulose capture	-	0.58	0.70	0.77	0.92	
	Cell. capt.(i)/Cell. capt.(PS)	-	1.00	1.22	1.33	1.60	
	BMP	ml CH4/g VS	315	350	340	270	
	BMP'	ml CH4	22.8	25.4	29.6	31.3	
	BMP'(i)/BMP'(PS)	-	1.00	1.11	1.30	1.37	
	TSS	mg	85	85	68	34	
Effluent	VSS	mg	72.5	72.5	58	29	Calculated Calculated Calculated
	COD	mg	315	315	247.5	202.5	
	TSS(i)/TSS(PS)	-	1.00	1.00	0.80	0.40	
	VSS(i)/TSS(PS)	-	1.00	1.00	0.80	0.40	
	COD(i)/COD(PS)	-	1.00	1.00	0.79	0.64	

* Median value of the results obtained from the literature and the other works carried out with the collaboration of Eawag