

# Rotating belt sieves for primary treatment, chemically enhanced primary treatment and secondary solids separation

B. Rusten, S. S. Rathnaweera, E. Rismyhr, A. K. Sahu and J. Ntiako

## ABSTRACT

Fine mesh rotating belt sieves (RBS) offer a very compact solution for removal of particles from wastewater. This paper shows examples from pilot-scale testing of primary treatment, chemically enhanced primary treatment (CEPT) and secondary solids separation of biofilm solids from moving bed biofilm reactors (MBBRs). Primary treatment using a 350 microns belt showed more than 40% removal of total suspended solids (TSS) and 30% removal of chemical oxygen demand (COD) at sieve rates as high as 160 m<sup>3</sup>/m<sup>2</sup>-h. Maximum sieve rate tested was 288 m<sup>3</sup>/m<sup>2</sup>-h and maximum particle load was 80 kg TSS/m<sup>2</sup>-h. When the filter mat on the belt increased from 10 to 55 g TSS/m<sup>2</sup>, the removal efficiency for TSS increased from about 35 to 60%. CEPT is a simple and effective way of increasing the removal efficiency of RBS. Adding about 1 mg/L of cationic polymer and about 2 min of flocculation time, the removal of TSS typically increased from 40–50% without polymer to 60–70% with polymer. Using coagulation and flocculation ahead of the RBS, separation of biofilm solids was successful. Removal efficiencies of 90% TSS, 83% total P and 84% total COD were achieved with a 90 microns belt at a sieve rate of 41 m<sup>3</sup>/m<sup>2</sup>-h.

**Key words** | municipal wastewater, particle separation, rotating belt sieves

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## INTRODUCTION

Fine mesh rotating belt sieves (RBS) offer a very compact solution for removal of particles, and they have been very successful for primary treatment of municipal wastewater (Rusten & Ødegaard 2006; Sutton *et al.* 2008; Franchi & Santoro 2015).

Commercial RBS units have a submerged belt area from about 0.1 m<sup>2</sup> to 2.2 m<sup>2</sup> per unit. For primary treatment of municipal wastewater the most common mesh size is 350 microns, but mesh sizes from 2 mm to below 30 microns are available. The sieves are modular and multiple units are used to accommodate large flows.

Particles larger than the mesh openings are collected on the belt, and gradually these particles will create a filter mat and remove particles significantly smaller than the mesh openings. This will reduce the flow through the belt, and the belt needs to rotate so that it can be cleaned and thereby sustain the necessary hydraulic capacity. The RBS can be operated with either a fixed belt speed and a variable water level, or a fixed water level and variable belt speed. The latter is most common, and

the belt speed will then depend on the water flow and the amount of suspended solids removed from the water. An air knife is normally used to blow the sludge off the belt, but scrapers and intermittent water spray have also been used.

A fairly recent RBS test of primary treatment at a municipal wastewater treatment plant (WWTP) in California (Franchi *et al.* 2012) showed between 30% and 65% total suspended solids (TSS) removal. This was achieved with a 350 microns belt at hydraulic sieve rates from 39 to 235 m<sup>3</sup>/m<sup>2</sup> submerged belt area-hour. Earlier tests in Norway showed that even higher removal efficiencies were possible with favourable wastewater characteristics and operating with a very thick filter mat and a low sieve rate. This type of operation resulted in 90% TSS removal and 80% biochemical oxygen demand (BOD<sub>5</sub>) removal with a 350 microns belt and a sieve rate of 25 m<sup>3</sup>/m<sup>2</sup>-h at the Breivika WWTP in Tromsø (Rusten & Ødegaard 2006).

As discussed in a recent paper (Rusten *et al.* 2016), several process consultants and end users believe that the fine

mesh RBS process removes too much organic material and that this is detrimental to a downstream biological process. This may, to a certain degree, be correct for processes with biological phosphorus removal (bio-P) and nitrogen removal by pre-denitrification, because these processes need readily biodegradable organic material. However, with fine mesh RBS and a proper control system, the process can easily be regulated to achieve a level of TSS and chemical oxygen demand (COD) removal suitable for the downstream biological process. This can be done by using the proper mesh size, belt speed and water level in each RBS unit, plus changing the number of units in operation. For the influent wastewater to two different WWTPs in Norway, it was found that the optimum RBS primary treatment, with respect to downstream biological nitrogen removal with pre-denitrification, was 40–50% TSS removal and 30–35% total COD removal (Razafimanantsoa *et al.* 2014; Rusten *et al.* 2016).

Some advantages of RBS include compact footprint, reduced civil engineering site work, and modular construction, the latter allowing for reduced design work, faster installation, and ease of plant expansion (Franchi & Santoro 2015).

In addition to conventional primary treatment, RBS technology is also emerging into enhanced primary treatment (adding coagulants and/or polymers in front of the sieves), as well as secondary solids separation downstream of fixed film biological processes. This paper shows examples of test results from all these different types of applications, based on recent experiments at municipal WWTPs in Norway.

## PRIMARY TREATMENT

At the Nedre Romerike WWTP (Strømmen, Norway) an RBS (see Figure 1), with a 350 microns belt and 0.5 m<sup>2</sup> submerged belt area, was installed and tested under a variety of operating conditions and hydraulic loads. The plant is in a rock cavern and had primary clarifiers followed by a MBBR process for nitrogen removal (Rusten & Paulsrud 2009). The objectives were (1) to see how much space can be saved by RBS primary treatment, (2) to produce a primary effluent that is optimum for the downstream pre-denitrification MBBR process, and (3) to produce a primary sludge with a higher methane gas potential (Paulsrud *et al.* 2014) for future anaerobic sludge digestion.

A total of 40 test runs were performed over a period of 3 months. Wastewater was pumped to the RBS from the influent channel, immediately after the sand traps, as shown in the simplified flow sheet in Figure 2. Wastewater temperatures were normally between 8 and 9 °C. Only one run had a temperature below 7 °C.

Each run had a predetermined constant flow. Influent and effluent water samples were collected as grab samples every 30 minutes, and identical volumes of each grab sample were mixed into a composite sample prior to analysis. As shown in Figure 2, influent samples were taken from a sampling point on the influent pipe, located downstream of the influent pump and a 90° bend, in order to ensure good mixing and representative sampling. Effluent samples were taken from a sampling point on the effluent pipe, located downstream of a bend in the pipe.

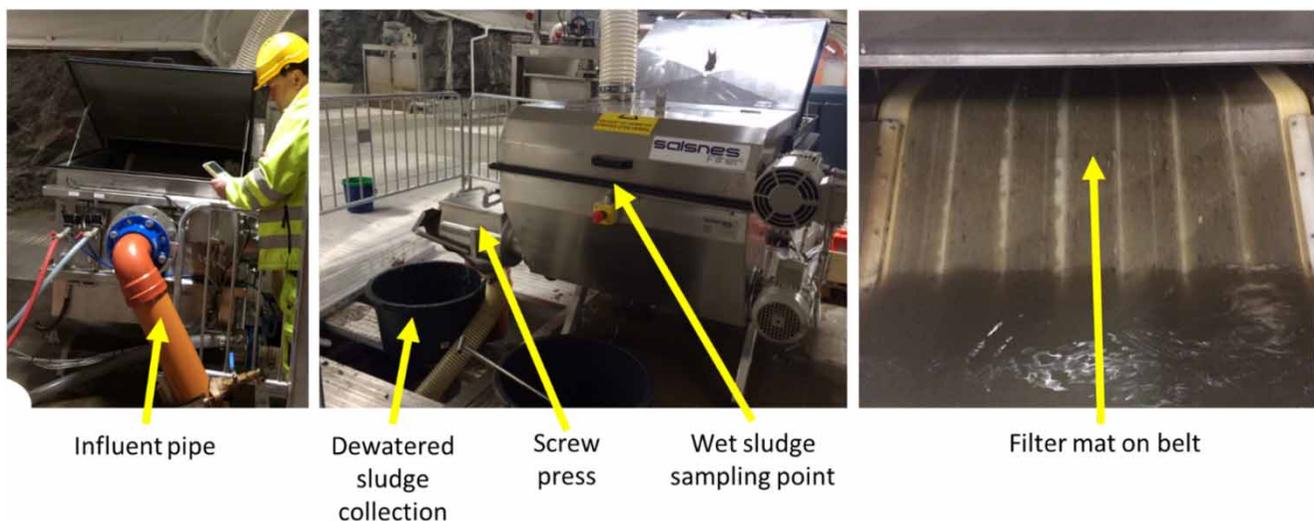


Figure 1 | RBS at the Nedre Romerike WWTP.

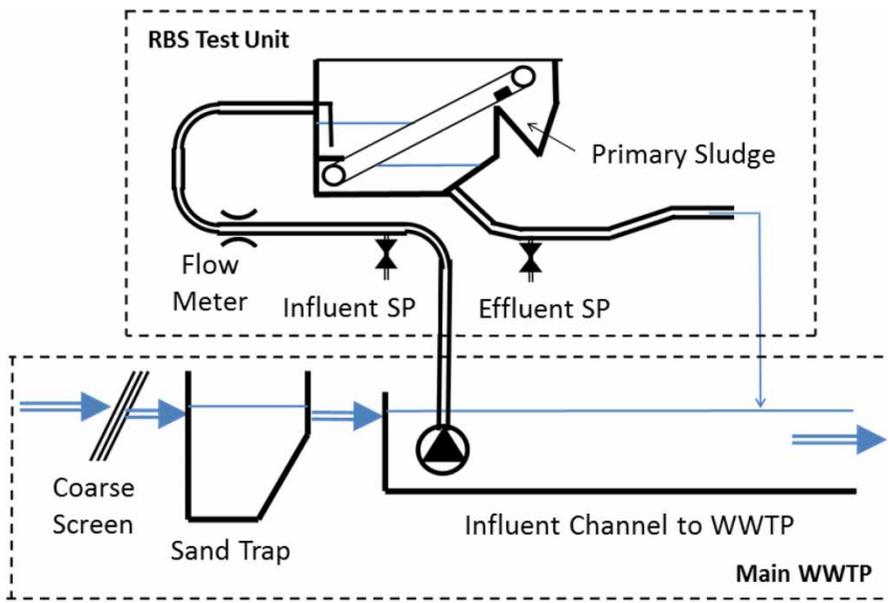


Figure 2 | Simplified flow sheet of the RBS test set-up at the Nedre Romerike WWTP. SP denotes sampling points for water samples.

Wet sludge was continuously blown off the belt by an air knife, and every 30 minutes a grab sample of this sludge was collected as it was falling into the sludge trough. The sampling point is indicated in Figure 1, and the cover had to be opened to access the wet sludge. Identical volumes of each sludge sample were later mixed into a composite sample for analysis. The entire production of dewatered sludge was collected in a container (see Figure 1) for each run and the total weight recorded. Multiple sub-samples

were collected from different locations in the dewatered sludge container, and then mixed to form a representative composite sample for analysis of the dewatered sludge.

In addition to wastewater characteristics being very important, removal rates and hydraulic capacity were influenced by water level and belt speed. The amount of particles deposited on the belt, prior to being blown off by the air knife, varied from below 10 to above 100 g TSS/m<sup>2</sup> and are shown in Figure 3. These particles created a filter mat that was important

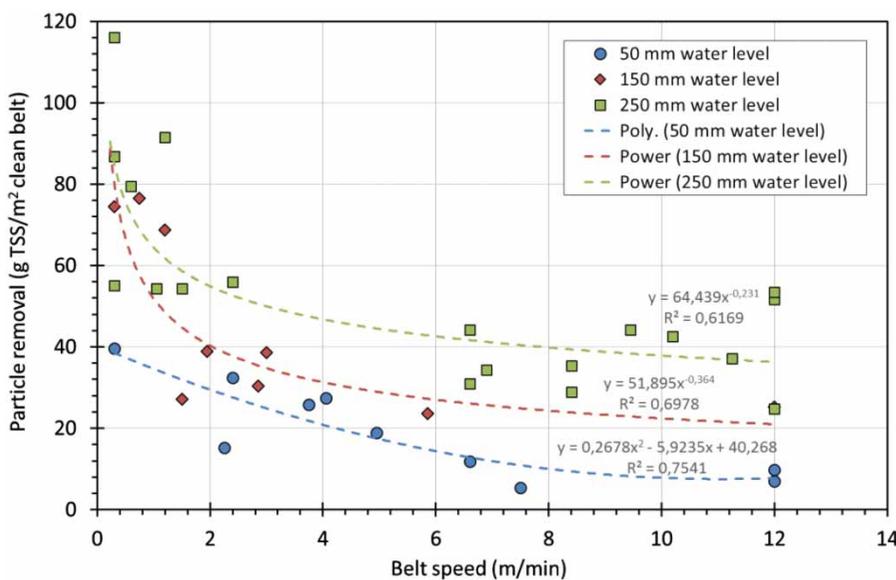


Figure 3 | RBS primary treatment at Nedre Romerike WWTP, showing the amount of particles deposited on the belt prior to removal by air knife, as a function of belt speed and water level on the inlet side of the sieve.

for the performance. Wet sludge blown off the belt had a dry solids (DS) concentration from 4 to 10%, depending on the belt speed. After dewatering in an integrated screw press, the median concentration was 25% DS. For dewatered sludge, volatile solids (VS) was  $89 \pm 4\%$  of the DS.

A mass balance can be performed by comparing the DS of the dewatered sludge to the amount of TSS removed based on influent flow and influent plus effluent TSS concentrations. Due to the many variables involved in such a mass balance calculation, the result will have a high uncertainty. Nevertheless, the calculation showed that, as an average for all the test runs, 87% of the TSS removed (based on influent and effluent TSS) was recovered in the dewatered sludge. With the very simple screw press used for dewatering in these tests, the difference can be assumed to be lost in the reject water. However, this result is not relevant for a full-scale RBS plant, since the wet sludge will be conditioned with polymer and dewatered in centrifuges with significantly higher solids recovery.

Figure 4 shows the TSS removal efficiency as a function of the sieve rate. Data are plotted for four different influent TSS concentration ranges as well as the three different water levels on the inlet side of the sieve. High influent TSS concentrations resulted in higher % removal of TSS than low influent TSS concentrations. More than 40% removal of TSS and more than 30% removal of COD were achieved

for all test conditions at sieve rates between 140 and  $160 \text{ m}^3/\text{m}^2$  submerged belt area-h.

The maximum sieve rate tested was  $288 \text{ m}^3/\text{m}^2\text{-h}$  and the maximum particle load was  $80 \text{ kg TSS}/\text{m}^2\text{-h}$ . For all sieve rates above approximately  $170 \text{ m}^3/\text{m}^2\text{-h}$ , the maximum water level of about 250 mm was needed to push the water through the sieve.

Table 1 shows key data for the test runs marked A, B and C in Figure 4. They are used to demonstrate the importance of the filter mat. Run A is an example of a very thin filter mat with visually very few particles on the belt. The water level on the inlet side of the sieve was only 50 mm and the belt speed was as high as 7.5 m/min, even though the sieve rate was only  $63 \text{ m}^3/\text{m}^2\text{-h}$ . This resulted in a filter mat of only  $5.3 \text{ g TSS}/\text{m}^2$  belt area, and the removal of TSS was only 22.4%.

Run B is an example of a very thick filter mat. The water level on the inlet side was 248 mm and the belt moved very slowly, at a belt speed of only 0.3 m/min. This resulted in a filter mat of  $87 \text{ g TSS}/\text{m}^2$  belt area. Together with a low sieve rate of  $46 \text{ m}^3/\text{m}^2\text{-h}$ , very good removal of TSS should be expected (Rusten & Ødegaard 2006), but the removal efficiency was only 33.7%. There are two reasons for this, firstly the very low influent concentration of 121 mg TSS/L (the lowest of all the 40 test runs), and secondly the low water flow resulting in a very high proportion of the water

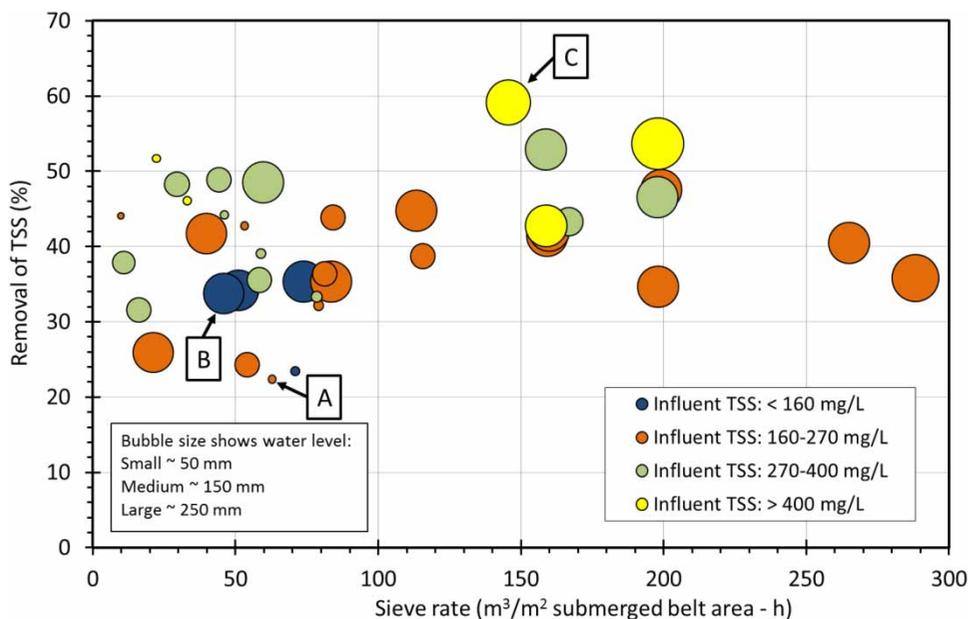


Figure 4 | RBS primary treatment at Nedre Romerike WWTP, showing the removal of TSS as a function of sieve rate, influent TSS concentration, and water level on the inlet side of the sieve. Further data for the three selected test runs marked A, B and C are shown in Table 1.

**Table 1** | RBS primary treatment at Nedre Romerike WWTP

	Run A	Run B	Run C
Sieve rate, m <sup>3</sup> /m <sup>2</sup> submerged belt area – hour	63	46	146
Water level on inlet side of sieve, mm	50	248	271
Belt speed, m/min	7.5	0.3	12.0
Particles deposited on belt (filter mat), g TSS/m <sup>2</sup>	5.3	86.7	53.4
Influent concentration, mg TSS/L	204	121	534
Removal efficiency for TSS, %	22.4	33.7	59.2
Removal efficiency for total COD, %	18.7	23.6	39.0

Shows key data for test runs marked A, B and C in Figure 4.

going through the lower part of the belt where there is no or only a very thin filter mat.

Run C is an example of a relatively thick filter mat that can be seen in the far right photo in Figure 1. The water level on the inlet side was 271 mm and the sieve rate was as high as 146 m<sup>3</sup>/m<sup>2</sup>-h. In spite of the belt moving at the maximum speed of 12 m/min, the filter mat was found to be as high as 53 g TSS/m<sup>2</sup> belt area. This was possible due to the combination of a high flow rate and a very high influent concentration of 534 mg TSS/L, the highest of all the 40 test runs. The removal efficiency for TSS was 59.2%. This was partly due to the high influent concentration, and partly due to the high flow rate that forced a significant fraction of the water to pass through the upper part of the sieve cloth (with a thicker filter mat) because the lower part of the sieve cloth rapidly reached the maximum hydraulic capacity for a clean cloth.

The achieved removal efficiencies, and the observations of how influent concentrations and RBS operational parameters influenced the removal efficiencies, were in agreement with the results found by Franchi *et al.* (2012) during a demonstration scale operation of an RBS unit at a WWTP in California, USA.

The Nedre Romerike WWTP has decided to replace existing primary clarifiers with RBS primary treatment. A contract is signed for an RBS installation for a maximum design flow of 5,040 m<sup>3</sup>/h. The goal is to operate the sieves at 40–50% removal of TSS, which is expected to be the optimum removal range with respect to the downstream pre-denitrification MBBR process (Rusten *et al.* 2016). This TSS removal can be achieved by the proper combination of water level, belt speed and number of sieves in operation. Higher TSS removal may remove too much COD and negatively influence the downstream pre-denitrification process.

The total area required for the RBS installation, including all channels and peripherals, is only 16% of the area required for primary sedimentation basins, if designed according to Norwegian guidelines (Norsk Vann 2009) with overflow rates of 2.4 m<sup>3</sup>/m<sup>2</sup>-h at average design flow and 4.8 m<sup>3</sup>/m<sup>2</sup>-h at maximum design flow. In addition, there is no need for primary sludge thickening when using RBS. This low space requirement for an RBS installation means significant savings for WWTPs that are located inside buildings or in rock caverns.

Removal efficiencies over the primary sedimentation basins have not been measured routinely at the NRA plant, since there is very little the operators can do to change the performance of the primary sedimentation process. However, during a study a few years ago, the primary sedimentation basins removed 58% SS and 47% total COD at the very low overflow rate of 1.4 m<sup>3</sup>/m<sup>2</sup>-h during a period of dry weather and low flow. This was slightly higher removal than the plant operators would prefer for optimum pre-denitrification conditions. With the new RBS primary treatment, the operators can actively change the removal of TSS and particulate COD, and thus have an additional tool to optimize the downstream pre-denitrification process.

## CHEMICALLY ENHANCED PRIMARY TREATMENT

Chemically enhanced primary treatment (CEPT) can be used to increase the removal of TSS and particulate COD, either because the wastewater is not suitable for primary treatment with fine mesh sieves (Rusten & Ødegaard 2006) or because the goal is to maximize the particle removal. Maximum removal of particles is beneficial for a situation where the objective is to recover as much energy as possible from the wastewater by producing biogas from the sludge, and at the same time reducing the energy requirement for aeration in a downstream biological process. Maximum removal of particulate COD is also compatible with downstream biological nitrogen removal using a mainstream deammonification process (Veuliet *et al.* 2015).

When chemical precipitation of phosphorus is not an objective, the simplest form of CEPT is to add a small amount of polymer directly upstream of the RBS. This has successfully been done at full-scale primary treatment RBS plants to improve the removal efficiencies. However, a systematic approach has been taken in an R&D project, using a pilot plant consisting of a dosing point for polymer,

rapid mixing, flocculation and the prototype of a small RBS, as shown in the photo in Figure 5.

Experiments were conducted at the Nordre Follo WWTP (Ås, Norway). A simplified flow-sheet of the set-up is shown in Figure 6. Wastewater was pumped from the influent channel, just downstream of the 3 mm screens, and to the pilot plant. Tests were performed as a worst case scenario, since a grinder pump was used to feed the pilot system and thus reduced the particle sizes in the wastewater.

The tank flocculator had a wet volume of 170 L and a variable speed stirrer with three blades. For all the tests

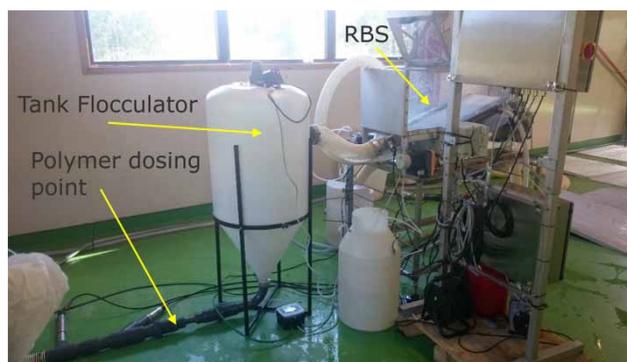


Figure 5 | Photo of the pilot-scale set-up for CEPT testing with prototype RBS.

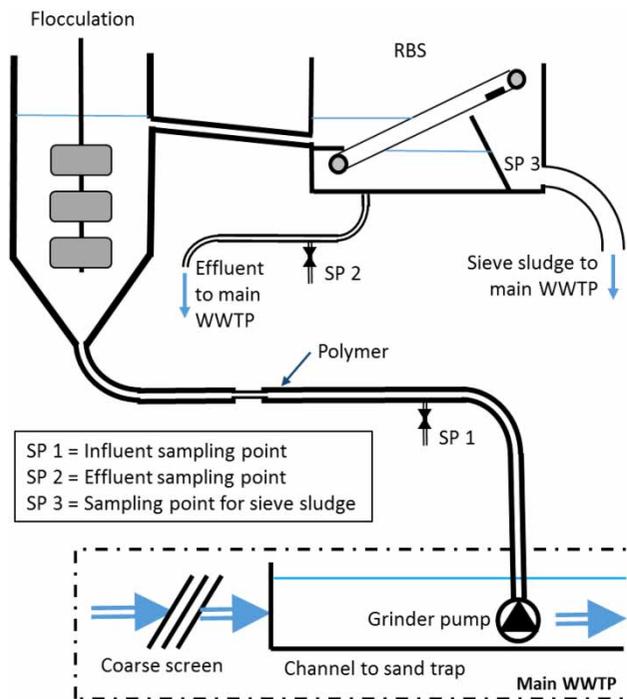


Figure 6 | Simplified flow sheet of the RBS set-up for CEPT testing at the Nordre Follo WWTP.

reported here, the stirrer speed was 60 rpm. The RBS had a belt angle of  $20^\circ$  and the control system was set to run the sieve with a water depth on the inlet side of 88 mm and a maximum belt speed of 4.3 m/min. The submerged belt area was  $0.09 \text{ m}^2$ . Collected solids were removed by a scraper, followed by an air knife to blow off any residual particles.

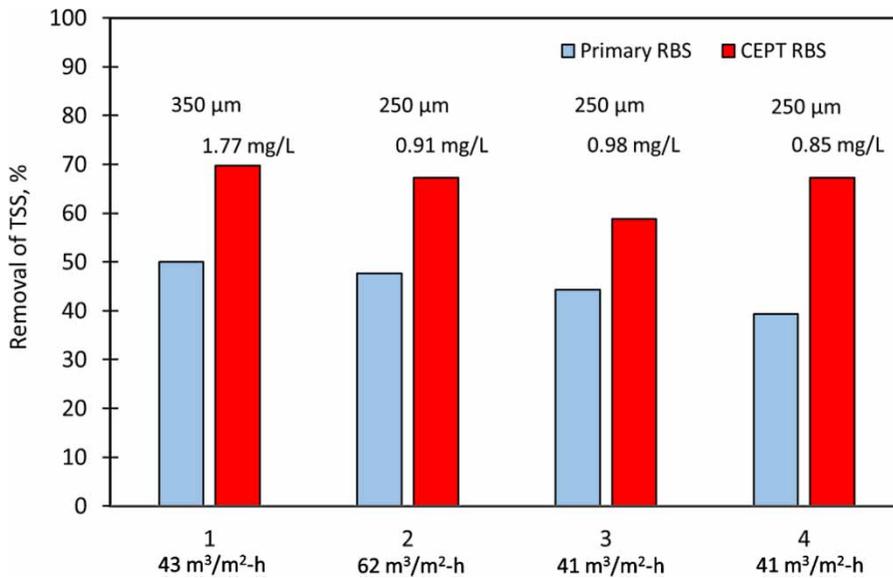
Belts with 250 microns and 350 microns openings were tested. Hydraulic retention times in the flocculator varied from 1.6 to 2.8 minutes. Hydraulic loads on the RBS varied from 40 to  $68 \text{ m}^3/\text{m}^2$  submerged belt area-h and were limited by the maximum capacity of the grinder pump.

Influent and effluent water samples, as well as samples of the wet sludge falling off the belt, were collected with the same procedure as previously described under the Primary Treatment section.

Some results are shown in Figure 7. Typically, a small amount of polymer (low cationic charge, very high molecular weight polyacrylamide) increased the removal efficiency by about 20 percentage points, from 40–50% TSS removal without polymer to 60–70% TSS removal with polymer. This increased removal efficiency is very important when the RBS is used as the only treatment step and the plant has to meet the EU requirements for primary treatment. It is very reassuring for the plant owners that if need be they can significantly increase the plant performance by adding a small amount of polymer.

The average removal efficiency (66%) for TSS shown for the CEPT process in Figure 7 was identical to the removal efficiency for the CEPT process at the Bangsund RBS plant (Rusten & Ødegaard 2006). Polymer doses were also similar. However, the Bangsund RBS plant was operated at a sieve rate of  $25 \text{ m}^3/\text{m}^2\text{-h}$ , while the runs in Figure 7 were performed at sieve rates from 41 to  $62 \text{ m}^3/\text{m}^2\text{-h}$ .

The particles scraped off the RBS belt had a concentration between 5 and 7% DS in most of the test runs. VS was measured on only a few samples and was 86–88% of DS. A methane potential test (Bioprocess Control AMPTS, Lund, Sweden) was performed with sieve sludge from primary treatment and CEPT, respectively. The test was run at the mesophilic temperature of  $37^\circ \text{C}$  and with sludge collected from run 4 in Figure 7. This test showed that the primary sieve sludge produced  $317 \text{ NmL CH}_4/\text{g VS}$ , while the CEPT sieve sludge produced  $483 \text{ NmL CH}_4/\text{g VS}$ . If the sludge goes to an anaerobic digester, this will be a great advantage for the CEPT sludge. It is not clear why the CEPT sludge had so much higher methane potential, but one hypothesis is that the smaller particles captured by the polymer are easier to degrade and contribute more biogas than larger particles.



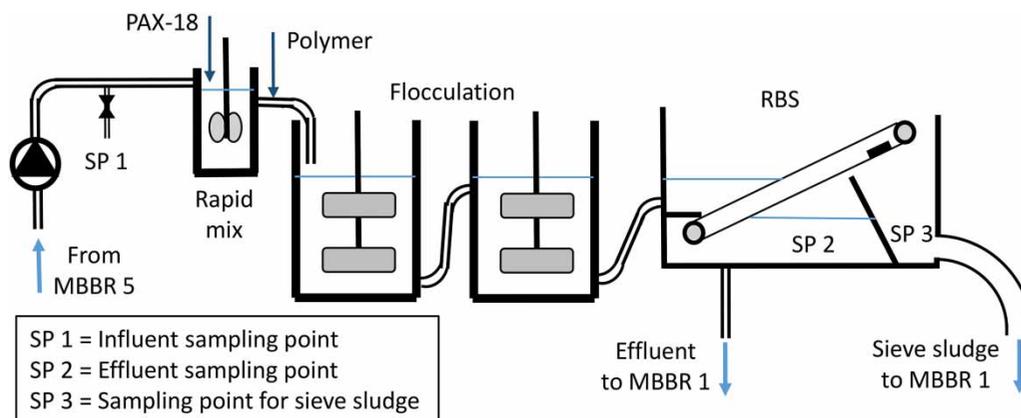
**Figure 7** | Results from pilot-scale CEPT testing with prototype RBS. Numbers above columns show openings in the belt and polymer dose. Numbers below show the test run and hydraulic load on the submerged belt area.

## SECONDARY SOLIDS SEPARATION

Separation of biofilm solids from MBBRs was tested at the Nordre Follo WWTP. A simplified flow-sheet of the test set-up is shown in Figure 8. This plant has 7 MBBR reactors in series, with post-denitrification and post aeration in reactors 6 and 7 (Rusten & Ødegaard 2007). Wastewater for biofilm solids separation testing was pumped from reactor 5, to provide biofilm solids from a typical MBBR process with pre-denitrification for nitrogen removal. Initial testing in a bench-scale tester indicated that without chemicals, very fine mesh sieves (11 microns) were necessary and the hydraulic capacity would be very low (Sahu *et al.* 2013).

Tests were continued in pilot-scale, using chemical addition, rapid mixing (20 seconds), two-stage flocculation (10 minutes at a G-value of  $66 \text{ s}^{-1}$ ), and a very early prototype of the small RBS.

PAX-18 and polymer (high cationic charge, high molecular weight polyacrylamide) were used for the RBS tests, with PAX added to the rapid mix tank and polymer dosed inside the tube connecting the rapid mix tank and the first flocculation tank. From jar tests, an optimum dose of  $13 \text{ mg Al/L} + 1 \text{ mg polymer/L}$  was found and then used in the pilot tests. Figure 9 shows an example of the flocs created in the flocculation stage and of the biofilm solids scraped off the RBS belt.



**Figure 8** | Simplified flow sheet of the RBS test set-up for separation of biofilm solids at the Nordre Follo WWTP.



**Figure 9** | Flocs from pilot-scale flocculation of MBBR effluent with PAX-18 and polymer (left), and scraper removing flocculated biofilm solids from the early prototype RBS belt (right).

For each test run, grab samples of water were taken at 15 minute intervals, for a total of 5 sets per run. For this early prototype RBS, the effluent samples (SP 2 in Figure 8) were collected directly from the back side of the belt. Each grab sample was analysed.

Different mesh sizes (from 33 up to 250 microns) were tested, and there was a significant decline in performance at mesh sizes above 90 microns. With 90 microns mesh and a hydraulic load of  $41 \text{ m}^3/\text{m}^2$  submerged belt area-h effluent concentrations of  $16 \pm 5 \text{ mg TSS/L}$ ,  $0.84 \pm 0.09 \text{ mg total P/L}$  and  $39 \pm 2 \text{ mg total COD/L}$  were found. This corresponded to removal efficiencies of 90% for TSS, 83% for total P and 84% for total COD, based on the concentrations leaving the biofilm reactor (SP 1) and the back side of the RBS belt (SP 2), respectively. The sludge scraped off the belt had 2% DS.

## CONCLUSIONS

Primary treatment at the Nedre Romerike WWTP with a RBS and a 350 microns belt showed that removal efficiencies and hydraulic capacities were dependent on influent concentrations, water level on the inlet side of the sieve and belt speed. Creation of a filter mat on the belt is important for high removal efficiencies. Results showed up to 60% TSS removal with a good filter mat, and less than 25% TSS removal with a very thin filter mat. Best results were achieved with maximum water level on the inlet side of the sieve and sieve rates in the range of  $140$  to  $160 \text{ m}^3/\text{m}^2\text{-h}$ . Sludge blown off the belt had from 4 to 10% DS.

CEPT is a simple and effective way of increasing the removal efficiency of RBS, and was tested at the Nordre Follo WWTP. With  $\sim 1 \text{ mg/L}$  of polymer and  $\sim 2$  min of flocculation time, the removal of TSS typically increased from 40–50% without polymer to 60–70% with polymer. Tests were

performed using the prototype of a small RBS with 250 or 350 microns belts and sieve rates from 40 to  $68 \text{ m}^3/\text{m}^2\text{-h}$ . Sludge scraped off the belt had typically 5 to 7% DS.

At the Nordre Follo WWTP separation of biofilm solids was successful, using coagulation and flocculation ahead of a very early prototype of the small RBS. Based on the concentrations leaving the biofilm reactor and the back side of the RBS belt, respectively, removal efficiencies of 90% TSS, 83% total P and 84% total COD were achieved with a 90 microns belt at a sieve rate of  $41 \text{ m}^3/\text{m}^2\text{-h}$ .

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