Microsieving in primary treatment: effect of chemical dosing

J. Väänänen, M. Cimbritz and J. la Cour Jansen

ABSTRACT

Primary and chemically enhanced primary wastewater treatment with microsieving (disc or drum filtration) was studied at the large pilot scale at seven municipal wastewater treatment plants in Europe. Without chemical dosing, the reduction of suspended solids (SS) was (on average) 50% (20–65%). By introducing chemically enhanced primary treatment and dosing with cationic polymer only, SS removal could be controlled and increased to >80%. A maximum SS removal of >90% was achieved with a chemical dosing of >0.007 mg polymer/mg influent SS and 20 mg Al<sup>3+</sup>/L or 30 mg Fe<sup>3+</sup>/L. When comparing sieve pore sizes of 30–40 μm with 100 μm, the effluent SS was comparable, indicating that the larger sieve pore size could be used due to the higher loading capacity for the solids. Phosphorus removal was adjusted with the coagulant dose, and a removal of 95–97% was achieved. Moreover, microsieving offers favourable conditions for automated dosing control due to the low retention time in the filter.

Key words | coagulation, flocculation, microsieving, primary wastewater treatment

INTRODUCTION

The growth of many cities increases the load of existing wastewater treatment plants (WWTPs). At the same time, space for expansion is often limited. The challenge ahead for many plants is, therefore, to increase treatment capacity without taking more land into use. One way to increase treatment capacity is to reduce the loading on the biological treatment, which can be accomplished by using chemically enhanced primary treatment (CEPT) (Parker et al. 2004). Another way is to apply high-rate separation methods to reduce the footprint for primary treatment, possibly also allowing for retrofit of existing clarifiers. For this purpose, fine mesh sieves, sometimes referred to as microsieves, can be used as an alternative to primary clarifiers as demonstrated by Rusten & Ødegaard (2006) and Franchi & Santoro (2015). In the study by Rusten and Ødegaard, fulfilment of the EU criteria of 20% removal of biochemical oxygen demand and 50% removal of suspended solids (SS) (according to Council Directive 91/271/EEC) was demonstrated at several Norwegian plants. Both studies, performed with rotating belts, also demonstrated the possibility of applying CEPT in combination with microsieving. This possibility has also been proven with another type of microsieve, the drum filter, by Ljunggren et al. (2007).

CEPT, preferably based on settling as the separation process, has been practiced for decades with or without downstream biological processes, especially in Scandinavia and North America but also in other parts of the world (Parker et al. 2004). If CEPT is applied prior to biological treatment, control of chemical oxygen demand (COD) removal is obviously of utmost importance to provide suitable conditions for conventional nitrogen removal. Removal efficiencies of 75–95% for COD, total phosphorus (TP) and SS are reported (Ødegaard 1992). Similar removal efficiencies for this type of wastewater have also been reported elsewhere (see, for example, Karlsson & Smith 1991; Andersson et al. 1992; Elia & Isolati 1992; Kristensen & Jorgensen 1992; Morrissey & Harleman 1992; Sarparastzadeh et al. 2007).

Recent publications also indicate the feasibility of utilizing microsieves in development of ‘energy-positive’ treatment schemes based on coagulation/flocculation to maximize removal of organics in the primary treatment. Remy et al. (2014) showed average SS reduction >95% and COD reductions on the order of 70–80% in a configuration based on coagulation/flocculation and drum filtration. The use of fine mesh sieves (rotating belts) to increase the
sludge energy potential has been demonstrated by Paulsrud et al. (2014). The same mesh and sieve type has also been used to study the effect on subsequent denitrification rates (Razafimananantsoa et al. 2014).

In 1998, Ødegaard presented research on chemical dosing in CEPT or, more precisely, on how organic polymers could be used as supplements to metal salts (Ødegaard 1998). Settling rates could be enhanced in this manner, but it was also shown that cationic polymers could replace, at least partly, metal salts to minimize sludge production. This possibility, with minimized sludge production, is interesting in the optimization of dosing in relation to microsieves.

In this paper, the results of seven large-scale pilot experiments with or without coagulation/flocculation and microsieving, using either disc or drum filters, are summarized. The effect of pore size and of chemical dosing, of both coagulant and polymer, on the effluent water quality have been studied. The aim of this study is to establish criteria for chemical dosing necessary for enhanced SS removal and to compare the results with traditional primary settling. The objective was also to study the effects on TP and COD removal and to propose a strategy for dosing control if the concept is to be combined with traditional biological nitrogen removal.

**METHODS**

Drum or disc filter units were supplied with woven polyester media with a sieve pore size of 30, 40 or 100 μm. Data for the pilot experiments are summarized in Table 1.

The filters and auxiliary equipment were supplied by Hydrotech, Veolia Water Technologies AB, Sweden. The operating principle of the disc and drum filter is described elsewhere (Ljunggren 2006). Below, in Figure 1, a schematic illustration of the pilot plants is shown.

Technical water was used for backwashing (3–5 bar). The pilot plants were supplied with raw municipal wastewater collected after the grit and sand removal. Flow was monitored by flow meters (Siemens Sitrans F M MAG 5100W, Germany). For coagulation and flocculation, square polyethylene vessels or stainless steel tanks were used. Coagulation and flocculation stirring devices were top-mounted, and stirrer motors (NORD Drivesystems AB, Sweden) were frequency controlled. The mixing intensity (G) was estimated to be approximately G ≈ 100 s⁻¹ for coagulation and flocculation at all pilot plants. Coagulant and polymer were dosed in-line under turbulent conditions. Coagulant and polymer dosing pumps were Alldos DDA...
and Alldos DME, Grundfos, Denmark, respectively. Coagulants were either polyaluminium chloride or iron chloride (FeCl₃). High molecular weight polymers, cationic or anionic, with low to medium charge density were used. Prior to the pilot experiments, screening for suitable chemicals for highest possible removal while keeping chemical consumption low was performed in the laboratory. SS were analysed according to Standard Methods (1989), while the chemical parameters COD (LCK 114/314), TP (LCK 348/349/350), total nitrogen (TN) (LCK 238/338) and ammonium (LCK 303) were analysed using colorimetric methods. A reasonable linear correlation between solids loading and backwash rate was used as the basis for a crude estimation of the solids loading capacities according to methodology presented by Ljunggren et al. (2007).

RESULT AND DISCUSSION

Removal without chemical pre-treatment

In Table 2, the influent wastewater quality and effluent wastewater quality for the different pilot experiments is presented. The average, minimum and maximum SS removal without chemical pre-treatment is shown. The overall conclusion was that sieve pore size <100 μm was unfavourable due to lower solids loading capacity with only a minor improvement in the SS removal. The results show that the average SS removal was, for the pore sizes 40 and 100 μm, 45–50% (minimum/maximum 20–65%) when no chemical pre-treatment was applied. Sieve pore size of 30 μm was also tested and increased the removal by approximately 15%. However, the trade-off by decreasing the sieve pore size was a major reduction in treatment capacity.

In comparison, SS removals of 30–65% with pore sizes ranging from 100 to 350 μm for microsieves constructed as rotating belt filters have been reported (Franchi & Santoro 2015). For primary settlers, SS removal of ≈30–70% is reported (Galil & Rehbnun 1990; Morrissey & Harleman 1992; Tchobanoglous et al. 2002). These results indicate that the removal efficiency in primary treatment using disc, drum, rotating belt microsieves or primary settlers is similar. Results will obviously be site- and time-specific.

Polymer dosing

With the addition of cationic polymer, SS removal can be enhanced (Figure 2). To observe an effect on the SS removal, a polymer dose of 0.003–0.005 mg polymer/mg influent SS was necessary. Wastewater containing 300 mg SS/L corresponds to a polymer dose of approximately 0.5–1 mg/L. Dosing more than 0.015–0.02 mg polymer/mg influent SS or approximately 4–5 mg/L for ordinary primary wastewater did not improve treatment results (Figure 2). At Källby WWTP, polymer dosing alone was reducing SS up to 95% (effluent SS 21 ± 14 mg/L). For Frederikshavn, an SS reduction of 82–89% was possible (effluent SS 42 ± 5 mg/L). Similar reduction could be achieved at Öresundsviken (87%, effluent SS 29 ± 6 mg/L) and at Klagshamn (90%, effluent SS 22 ± 5 mg/L).

Polymer and metal salt dosing

Similar SS reduction was also obtained for the other test sites with the same relative polymer dosing, but here, the polymer dosing had to be combined with coagulant dosing upstream to obtain the required destabilization of the suspension. The Källby and San Rocco WWTP experiments were performed with both cationic and anionic polymers and, in Figure 3(a), the results for both polymer types are presented. The polymers had similar molecular weight and charge density. For coagulant doses ≥5 mg Al³⁺/L both...

Figure 1 | Schematic illustration of the pilot plants (within the dashed line) and the general pre-treatment process for the test sites.
Table 2 | Influent wastewater quality (average and standard deviation) during the experiments and SS removal

<table>
<thead>
<tr>
<th></th>
<th>Källby WWTP (S)</th>
<th>Knislinge WWTP (S)</th>
<th>Klagshamn WWTP (S)</th>
<th>Frederikshavn WWTP (DK)</th>
<th>Sjölunda WWTP (S)</th>
<th>Öresundsverket WWTP (S)</th>
<th>WWTP San Rocco (IT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS (mg/L)</td>
<td>534 ± 173 (n = 73)</td>
<td>238 ± 51 (n = 30)</td>
<td>290 ± 243 (n = 28)</td>
<td>266 ± 129 (n = 12)</td>
<td>278 ± 174 (n = 60)</td>
<td>229 ± 73 (n = 25)</td>
<td>167 ± 80 (n = 11)</td>
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<tr>
<td>TP (mg/L)</td>
<td>14 ± 5 (n = 64)</td>
<td>5 ± 1 (n = 49)</td>
<td>6 ± 1 (n = 3)</td>
<td>7 ± 1 (n = 12)</td>
<td>7 ± 2 (n = 45)</td>
<td>7 ± 2 (n = 12)</td>
<td>4 ± 0.5 (n = 11)</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>712 ± 225 (n = 45)</td>
<td>397 ± 96 (n = 49)</td>
<td>–</td>
<td>430 ± 208 (n = 6)</td>
<td>648 ± 318 (n = 49)</td>
<td>487 ± 126 (n = 7)</td>
<td>352 ± 79 (n = 8)</td>
</tr>
<tr>
<td>CODsol* (mg/L)</td>
<td>82 ± 29 (n = 14)</td>
<td>137 ± 31 (n = 49)</td>
<td>–</td>
<td>128 ± 46 (n = 6)</td>
<td>226 ± 79 (n = 47)</td>
<td>–</td>
<td>175 ± 50 (n = 7)</td>
</tr>
<tr>
<td>NH4-N (mg/L)</td>
<td>31 ± 9 (n = 19)</td>
<td>21 ± 3 (n = 20)</td>
<td>31 ± 5 (n = 22)</td>
<td>–</td>
<td>29**</td>
<td>–</td>
<td>20 ± 2 (n = 2)</td>
</tr>
<tr>
<td>TN (mg/L)</td>
<td>59 ± 8 (n = 4)</td>
<td>38 ± 10 (n = 14)</td>
<td>–</td>
<td>46 ± 21 (n = 6)</td>
<td>–</td>
<td>36***</td>
<td>23 ± 13 (n = 8)</td>
</tr>
<tr>
<td>No chemical pre-treatment</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Sieve pore size (μm)</td>
<td>30/40/100</td>
<td>100</td>
<td>40</td>
<td>100</td>
<td>40</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Average/min/max SS removal (%)</td>
<td>30 μm 66/55/71 40 μm 45/26/46 100 μm 43/28/49</td>
<td>58/47/65</td>
<td>61/52/65</td>
<td>53/41/65</td>
<td>48/41/55</td>
<td>45/26/59</td>
<td>31/20/46</td>
</tr>
</tbody>
</table>

n – number of samples.
*Soluble COD filtered through 0.45 μm membrane filters.
**VA SYD (2013).
***NSVA (2014).
polymers displayed similar treatment results. Thus, anionic polymer was also applicable if combined with coagulant (Figure 3(a)). If low SS in the effluent was required (<10 mg/L), higher coagulant dosing was generally necessary (Figure 3(b)). The coagulant improved the SS removal by only 10%, even with very high dosing (≈20 mg Al³⁺/L).

The sludge production was approximately 1–5% of the treated flow, and the total solids content in the produced sludge ranged from 0.5–2%, in agreement with previous studies (Remy et al. 2014). Moreover, this type of sludge has been reported to generate more biogas. With similar methane content in the produced gas (60%) and with approximately a 50% rate of degradation of the organic dry matter, a specific biogas production of 600 normal L/kg organic dry matter input has been reported. This value is to be compared to 430 normal L/kg organic dry matter input for ordinary mixed sludge (Remy et al. 2014).

The significant effect of relatively low doses of polymer also indicates the importance of applying dosing control to reduce chemical usage. As the polymer dose (cationic) is influencing the SS removal most significantly, controlling the water quality could be based on the dosing of polymer. If additional destabilization of the suspension is required, the coagulant dosing can be adapted relative to the polymer dosing. With this dosing strategy, phosphorus removal could also be controlled to a higher extent.

Effluent SS concentrations in the range of 50–70 mg/L for similar relative polymer dosing (0.003–0.012 mg polymer/mg influent SS) have been reported by Rusten & Ødegaard (2006) applying rotating belt microsieves (250 μm) in primary treatment. Effluent SS concentration in this range has also been reported for CEPT in combination with settling. (Karlsön & Smith 1991; Andersson et al. 1992; Elia & Isolati 1992; Kristensen & Jørgensen 1992; Morrissey & Harleman 1992; Sarparastzadeh et al. 2007). The coagulant dose for CEPT and settling was ≈4–20 mg Al³⁺/L or 7–40 mg Fe³⁺/L, and the polymer dose was in the range of 0.25–0.8 mg/L (≈0.002 mg polymer/mg influent SS). Thus, in the CEPT configuration, for similar chemical dosing (active polymer + Me³⁺), microsieving with disc/drum or with rotating belt filters shows SS removal efficiencies comparable to settling. However, microsieves generally require somewhat higher polymer dosing, which can be compensated by a lower coagulant dosing for the same SS removal as in settling.

**Control of COD and P**

The results show a possibility of adapting SS removal by controlling polymer dosing and therefore, to some extent, also the COD removal. This adaptation would affect effluent wastewater characteristics such as the COD/N ratio. By
introducing coagulant dosing, it was shown that SS and COD removal can be enhanced even further and that phosphorus removal can be controlled. This control of effluent wastewater characteristics provides opportunities to control the influent COD for biological nitrogen removal and to optimize anaerobic digestion for biogas production. In the following section, the effect of chemical pre-treatment on COD and TP are discussed based on three case studies, namely, Källby, Knislinge and Sjölunda WWTPs.

As guidance, a minimum COD/N ratio of approximately 4–6 is recommended for primary treated municipal wastewater (Henze et al. 2002) for sufficient biological nitrogen removal. With this ratio, the aim is for a COD concentration in the range of 150–300 mg/L. Additionally, some phosphorus is also required, and 0.5–1 mg TP/L is a general recommendation (ATV 2000). Due to the high SS removal, the majority of the nitrogen will be ammonium nitrogen. Therefore, the COD/NH₄-N ratio is used in the discussion.

The results from Källby WWTP (100 μm media pore size) show that an appropriate polymer dose would be approximately 0.005 mg polymer/mg influent SS with or without a low dose of coagulant (Figure 4(a)) to achieve approximately 200 mg COD/L for an appropriate COD/NH₄-N ratio of 6–7. Polymer dosing alone was able to produce an effluent almost entirely consisting of soluble COD (COD ≈ 61 mg/L, effluent SS ≈ 10 mg/L, Figure 2).

Phosphorus limitation would not become as critical if only polymer is used. If coagulant is added with a relative dose of >1 mg Al³⁺/mg influent TP (which for this site corresponded to approximately 10–20 mg Al³⁺/L), problems in the downstream biological treatment stage related to phosphorus limitations might occur. TP concentration for this dose was measured to be in the range of 0.07–0.3 mg TP/L (Figure 4(b)).

In Figure 5, below, the results from Knislinge WWTP are displayed. One difference between Knislinge and Källby WWTPs was a more diluted wastewater with a higher content of soluble COD at Knislinge.

In this case, appropriate chemical dosing for the recommended COD/NH₄-N ratio and phosphorus content would be approximately 0.01 mg polymer/mg influent SS, combined with a low dose of coagulant of approximately 1.5 mg Al³⁺/mg influent TP. For the average influent water quality at Knislinge WWTP, this appropriate chemical dosing would be approximately 2–2.5 mg polymer/L and ≈7 mg Al³⁺/L. With this chemical dose, the effluent would contain approximately 200 mg COD/L and approximately 1 mg TP/L (Figure 5(a) and 5(b)). For higher chemical dosing (>0.015 mg polymer/mg influent SS, >2 mg Al³⁺/mg influent TP), the COD content in the effluent could be insufficient for denitrification (Figure 5(a)), but there might also be a risk of phosphorus limitation (Figure 5(b)).
For the Sjölunda WWTP, in most cases, an appropriate COD/NH₄-N ratio would prevail independently of the polymer and coagulant dose, at least in the range of 0.005–0.03 mg polymer/mg influent SS and at a relative iron dose of 1.5–2 mg Fe³⁺/mg influent TP or approximately 2–4 mg polymer/L and 10 mg Fe³⁺/L. In this case, controlling SS removal would not be as crucial to have sufficient COD concentrations in the effluent. With this dose, an effluent low in SS concentration (SS 10–30 mg/L, Figure 3(a)) containing 200 mg COD/L would be the result from CEPT, and the COD/NH₄-N ratio would be approximately 7. At Sjölunda, more attention must be paid to limit chemical dosing to avoid phosphorus limitations (Figure 6(b)).

**Solids loading**

Table 3 shows the solids loading capacity without chemical pre-treatment. The solids loading capacity was 3–10 kg SS/m²h for 100 μm sieve pore size, 4–5 kg SS/m²h for 40 μm and for 30 μm, approximately 2 kg SS/m²h. The results also show that the variation is relatively large, and this large variation is expected due to variations in wastewater characteristics and due to fouling that are not removed by the ordinary backwash.

During the experiments when cationic polymer dosing was applied at a relative low polymer dose, the solids loading capacity initially decreased to approximately half. With increased dosing, the solids loading capacity increased, and at optimal polymer dosing, the solids loading capacity was higher than initially recorded without chemical pre-treatment. If a sufficient relative polymer dosing were applied, then the additional solids loading produced from the coagulant had a minor effect on the solids loading capacity and was similar to the situation without chemical pre-treatment. Sizing of the microsieves would, in addition to the wastewater characteristics and media pore size, also be a function of the operational strategy (with or without chemical pre-treatment and high/low chemical dosing).

The similar effect that the chemical dosing has on effluent SS, TP and, to some extent, COD concentrations and SS (turbidity) is relatively easy to measure online (Mels et al. 2013). CEPT based on microsieving seems to offer favourable conditions for automation and control. The short retention time and the consistent effluent water quality despite variations in hydraulic loading for the CEPT and microsieving process is also a factor indicating that controllers could be successfully implemented. Future experiments on controlling CEPT and microsieve effluent water quality are therefore planned.

In reviewing literature and comparing the results from this study, both settling and microsieving technologies show comparable removal efficiencies and also total chemical consumption in primary treatment. Similar chemical
operational costs could be expected, but the microsieve technology is regarded as more space effective (Wilén et al. 2012; Franchi & Santoro 2015). Replacing conventional primary clarifiers with microsieves could free volumes for biological treatment. Moreover, for microsieves in primary treatment, the results from this study and from other studies (Rusten & Ødegaard 2006) indicate that the most economical dosing range would be 4–7 mg/L of active material (active polymer + Me³⁺) as dosing either with only polymer or in combination with a low coagulant dose (≤5 mg/L).

Table 4 shows general recommendations on how microsieves can be implemented in primary treatment of municipal wastewater. Dosing interval and expected removal efficiencies and effluent SS, COD and TP concentrations are shown.

## CONCLUSIONS

1. In general, for microsieving (100 μm), a 50% SS removal is obtained without chemical pre-treatment. Removal >95% can be achieved if microsieving (100 μm) is combined with CEPT. Removal of SS and the amount of chemical dosing is in the same range for the two separation technologies (microsieving and settling).
2. Polymer dosing should be the primary flocculating agent and be adapted to the influent SS, and the coagulant dosing should be related to the polymer dosing for additional SS and total phosphorus removal.
3. To obtain 80–90% SS reduction, the relative cationic polymer dose to the influent SS would be in the range of 0.005–0.01 mg polymer/mg influent SS. For higher removal

REFERENCES

ACKNOWLEDGEMENTS

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Table 4 | General recommendations and scenarios for microsieves in primary treatment regarding chemical dosing interval, expected removal and effluent concentrations and objectives

<table>
<thead>
<tr>
<th>Chemical dosing range</th>
<th>Expected removal (%) and effluent concentrations (mg/L)</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microsieving only</td>
<td>SS 50%</td>
<td>Replace primary settling</td>
</tr>
<tr>
<td></td>
<td>COD 20%</td>
<td>Save space</td>
</tr>
<tr>
<td></td>
<td>TP 20%</td>
<td></td>
</tr>
<tr>
<td>Cationic polymer + microsieving</td>
<td>SS 80–90%/20–40 mg/L</td>
<td>Save space</td>
</tr>
<tr>
<td></td>
<td>COD 70–90%/60–200 mg/L</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TP 50–90%/2–5 mg/L</td>
<td></td>
</tr>
<tr>
<td>Coagulant + polymer + microsieving</td>
<td>SS &gt;95%/ &lt; 20 mg/L</td>
<td>Low additional chemical sludge production</td>
</tr>
<tr>
<td></td>
<td>COD 70–95%/50–200 mg/L</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TP &gt;95%/ &lt; 0.3 mg/L</td>
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</tbody>
</table>

*Depending on influent wastewater characteristics, particulate/dissolved COD and TP.


 (>95%), 0.01–0.02 mg/L could be necessary and in combination with 10–20 mg Al^{3+}/L or 20–40 mg Fe^{3+}/L. For ordinary municipal wastewater containing 300 mg SS/L, this concentration would correspond to a polymer dose of 1.5–2.1 mg/L and 3–6 mg/L of metal salt, respectively. If anionic polymer is applied, the anionic polymer must be combined with a coagulant dose of approximately 5 mg Me^{3+}/L or higher.

4. The more space-effective microsieve technology allows for primary clarifiers to be retrofitted. Treatment capacity can be increased in the existing treatment volumes. If introducing CEPT prior to the microsieve technology, treatment capacity can be increased even further.


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