Mechanical pre-treatment (MPT) – revitalised by MBR process

ABSTRACT
Since the mid-nineties membrane bioreactor (MBR) technology has been introduced to municipal wastewater treatment in Europe. The first MBR plants went into operation performing a conventional mechanical pre-treatment (MPT) without any advanced treatment units. After a short operation period, clogging caused by fibrous substances and hence module sludging was observed. Thus, MPT was upgraded introducing sieves. Several investigations had been carried out to determine the removal efficiency of different sieve units and entire MPT systems. Meanwhile experiences from long-term operation at different MBR sites indicate dependencies between different MPT units, especially between the aerated grit chamber/grease trap and the subsequent sieve unit. Usually the sieve is the final MPT unit and its performance depends on the performance of the upstream MPT units. This report describes and discusses results from a research project at MBR Kaarst–Nordkanal in Germany conducted in 2008 to 2010 by the Water Board of River Erft and the Department of Sanitary and Environmental Engineering. Main focus is addressed for the parameters SS (settable solids) and grease. One major experience is the confirmation of relevant interactions between the grit chamber and the downstream sieve unit. Stable operation of the grit chamber and grease trap is essential to achieve a constantly high removal performance of the sieve unit and therefore the entire MPT stage. In turn, negative impacts on the grit chamber performance from the return flow concept have to be avoided. Finally, it is shown that the appropriate two-dimensional sieve gap size should not go beyond 1 mm when operating hollow fibre membranes.

Key words | advanced mechanical pre-treatment (aMPT), aerated grit chamber/grease trap, MBR, sieve

INTRODUCTION
For a long time little scientific attention was given to mechanical pre-treatment (MPT) such as screens, grit chambers or grease traps. Probably most work concerning MPT processes was dedicated to primary sedimentation tanks and its influences on biological P-removal or anaerobic sludge stabilisation.

With the introduction of membrane technology into municipal wastewater treatment, resulting in so called membrane bioreactor (MBR) plants, things have changed. In order to operate MBR plants stably and safely, an advanced MPT (aMPT) of the raw water including sieve units is essential. This is a prerequisite to avoid clogging and sludging on the membrane modules that inevitably lead to an increase of the hydraulic resistance.

The difference to conventional MPT systems prior to conventional activated sludge systems (CAS) are shown in Figure 1. It is important to note that most MBR plants apply aerobic simultaneous sludge stabilisation and therefore do not operate a primary sedimentation. Typically, the aMPT of MBRs is designed either single-staged (fine screen or fine sieve) or two-staged (screen and sieve) in addition to a grit chamber/grease trap which is essential for every type of wastewater treatment plant (WWTP).

With respect to the undesirable influence of fibrous material, it is generally agreed that flat sheet membrane modules are a little less sensitive because they show less tendency of accumulation and sticking of fibrous material compared with hollow fibre membranes (Judd 2006; Churchouse et al. 2007; CEN 2008; Frechen 2009).
For this reason today flat sheet MBRs are mostly equipped with single-staged MPT covering a fine screen with two-dimensional gap sizes of 2 to 3 mm. In contrast, aMPT at hollow fibre MBRs are constructed predominantly two-staged comprising both fine screen and fine sieve, the latter with two-dimensional gap sizes of 1 to 1.5 mm. The classification of screens and sieves based on German DWA guidelines (DWA 2011) and are shown in Table 1.

Past investigations concerning aMPT in MBRs focused on the efficiency of the sieving unit itself with respect to the removal of hair, fibres, SS (settable solids) and other basic wastewater parameters. Results of such investigations on German and other European MBR plants were reported by our group and other authors (Frechen et al. 2006; Rusten & Ødegaard 2006; Schier et al. 2009). A summary showing SS and chemical oxygen demand (COD) removal observed with different types of screens and sieves is given in Table 2.

For the research work presented here the scope was extended. Former investigations at the two-staged aMPT on Germany’s largest MBR plant in Kaarst–Nordkanal, as well as an evaluation of French municipal and industrial MBR plants (Lazarova et al. 2008; Lazarova et al. 2009) and results from the Dutch MBR Varsseveld (STOWA 2002) indicated a relationship between a reliable performance of the sieve unit and the stable operation of the upstream process units, in particular the aerated grit chamber and grease trap. Too high concentrations of SS or grease may seriously disturb the sieve operation and its removal performance.

It seems obvious that – compared with MPT in conventional plants – aMPT in MBRs is more sensitive and requires higher process quality of the upstream grit chamber. To date, the issue of braid formation occurring at the membrane modules has not been completely solved. Insufficient aMPT causing the clogging of screens and sieves is the most common failure in MBR operation (Lazarova et al. 2008).

These observations and findings at different MBRs in Europe led to a research project conducted by the Water Board of River Erft and the Department of Sanitary and Environmental Engineering. Major goals of this project that ended in 2010 were:

- mass balances concerning entire MPT system with special regard to SS and grease;

### Table 1: Characteristics of screens and sieves (DWA 2011)

<table>
<thead>
<tr>
<th>Screens</th>
<th>One-dimensional (slit: horizontal, vertical)</th>
<th>Two-dimensional (hole)</th>
<th>Sieves</th>
<th>One-dimensional (slit)</th>
<th>Two-dimensional (hole, mesh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>50–20 mm</td>
<td>–</td>
<td>Coarse</td>
<td>≥1 mm</td>
<td>≥1 mm</td>
</tr>
<tr>
<td>Middle</td>
<td>20–10 mm</td>
<td>–</td>
<td>Fine</td>
<td>&lt;1 mm</td>
<td>0.2–1 mm</td>
</tr>
<tr>
<td>Fine</td>
<td>10–2 mm</td>
<td>12–2 mm</td>
<td>Micro</td>
<td>–</td>
<td>&lt;0.2 mm (mesh)</td>
</tr>
</tbody>
</table>
achieving an improved and stable operation of the entire aMPT system by optimising the operation and efficiency of each MPT unit;
sieve performance under different hydraulic conditions;
comparison of conventional (covering primary sedimentation) and aMPT systems.

The investigations were carried out at MBR Kaarst–Nordkanal (serving 80,000 p.e.) using a two-staged aMPT. Selected results are subsequently reported.

FUNDAMENTALS AND METHODS

Detailed description of the entire treatment process at MBR Kaarst–Nordkanal is given in Engelhardt et al. (2007) and Brepols (2010). Advanced MPT at MBR Kaarst–Nordkanal includes a 5 mm step screen, an aerated grit chamber/grease trap and two rotating drum sieves. The design of the sieves has already been upgraded twice. Initially, the aMPT concept comprised two 0.5 mm slit rotating drum sieves which were substituted in 2006 by two 1 mm mesh rotating drum sieves. In 2010 the mesh size was enlarged to 1.5 mm.

For reasons of redundancy the emergency bypass is equipped with a 1 mm rotating drum sieve with slit geometry. This sieve was observed frequently to start operation at noon in times of dry weather flow (dwf) but not in times of rainwater flow. This led to the assumption of a permanent, or at least sporadic, increased SS load rate to the main sieves. It was assumed that cleaning mechanism of the main sieves cannot cope with the high amount of SS and the retained material builds a layer on the sieve surface. Thus, the water level in front of the main sieves rises until the point at which the emergency bypass is put into operation.

First measurements were carried out in June 2008 to determine the actual status of aMPT efficiency. Sampling and analysing covered all liquid and solid media. Figure 2 shows the sampling scheme of the liquid media.

The main parameters measured were SS, COD and grease. Routinely at WWTPs such parameters are analysed from daily composite samples of 1 to 2 L. However, to increase the correctness and accuracy of the measurement it was necessary to collect larger sample volumes. For this purpose filter bags with a pore size of 0.19 mm were applied. Samples of 10 L volume were manually filtered every 15 min giving a total sample volume of 80 L over a 2 h period. By this means it was also possible to split the obtained material into individual fractions, i.e. coarse SS (>0.2 mm) and fine SS (<0.2 mm) as well as organic and mineral SS. Separate

Table 2 | SS and COD removal rates of sieve units in aMPT systems

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaarst</td>
<td>Band</td>
<td>Mesh</td>
<td>0.35</td>
<td>287</td>
<td>159</td>
<td>45</td>
<td>835</td>
<td>655</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Drum</td>
<td>Slit</td>
<td>0.50</td>
<td>400</td>
<td>350</td>
<td>13</td>
<td>828</td>
<td>743</td>
<td>10</td>
</tr>
<tr>
<td>Markranstädt</td>
<td>Drum</td>
<td>Slit</td>
<td>0.75</td>
<td>460</td>
<td>388</td>
<td>16</td>
<td>749</td>
<td>600</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Drum</td>
<td>Mesh</td>
<td>0.75</td>
<td>529</td>
<td>391</td>
<td>26</td>
<td>1,126</td>
<td>746</td>
<td>34</td>
</tr>
<tr>
<td>Varsseveld</td>
<td>Half drum</td>
<td>Hole</td>
<td>0.80</td>
<td>333</td>
<td>265</td>
<td>20</td>
<td>619</td>
<td>564</td>
<td>9</td>
</tr>
<tr>
<td>Kaarst</td>
<td>Band</td>
<td>Mesh</td>
<td>0.84</td>
<td>416</td>
<td>291</td>
<td>31</td>
<td>576</td>
<td>438</td>
<td>24</td>
</tr>
<tr>
<td>Monheima</td>
<td>Drum</td>
<td>Slit</td>
<td>1.00</td>
<td>486</td>
<td>312</td>
<td>36</td>
<td>840</td>
<td>804</td>
<td>4</td>
</tr>
<tr>
<td>Kaarst</td>
<td>Drum</td>
<td>Mesh</td>
<td>1.00</td>
<td>367</td>
<td>255</td>
<td>31</td>
<td>337</td>
<td>253</td>
<td>25</td>
</tr>
<tr>
<td>Varsseveld</td>
<td>Half drum</td>
<td>Hole</td>
<td>1.50</td>
<td>568</td>
<td>524</td>
<td>8</td>
<td>337</td>
<td>253</td>
<td>25</td>
</tr>
</tbody>
</table>

aThe aMPT at MBR Monheim does not include a screen; the sieve is operated as the first removal stage.
analyses of these fractions were helpful to evaluate the grit chamber efficiency according to German Standard DIN 19569-2 (2002) requiring a minimum removal of 95% concerning SS_{mineral} of a grit size >0.2 mm.

Additionally manual 2h-composite sampling was made for COD and grease determination. Sampling was carried out for 8 h a day from 8 a.m. to 4 p.m. The method is illustrated in Figure 3.

RESULTS AND DISCUSSION

The efficiency of each aMPT unit is presented in Figure 4. It shows the course of load rates of COD, SS, grease_{tot} along the aMPT system from the sampling campaign in summer 2008 and the accordingly statistical box-whisker plots (including maximum, third quartile, median, first quartile and minimum).

The results are quite astonishing. Thus, grit chamber and grease trap (g_c/g_t) seem not to remove any of the investigated pollutants, neither COD nor SS (including the targeted fraction of SS_{mineral}, >0.2 mm) or grease. In contrast, screen and sieve work as they are supposed to do. The removal rates of the screen are in the same range as similar units at other plants.

The SS removal rates of the sieve are comparatively high and amounted on average to 44%. Investigations at other European MBRs with sieves of hole or mesh geometry in the dimension of ≤1 mm showed SS removal rates of just 25 to 30% (Schier et al. 2009).

A principal question deriving from Figure 4 is: why is the SS load rate unexpectedly increasing while passing the grit chamber/grease trap? There are several aspects and influences that have to be discussed.

**Hydraulic retention time (HRT) and grit chamber aeration**

The grit chamber is designed, according to common practise, in a way that the theoretic hydraulic retention time (HRT) is 20 min at dry weather flow (dwf) and down to 10 min at rain weather flow (rwf). These are the correct hydraulic design criteria with respect to German guidelines including the above mentioned German Standard DIN 19569-2 (2002). The geometric design rules have been followed too. However, in practice due to the low wastewater flow at night time the retention time increased up to 2 h and more. It is presumed that – despite the mixing through aeration – a storage effect occurs in this period. Later on during daytime when the hydraulic load increases, accumulated pollutants are remobilised. This might be caused by the specific design of the grit chamber featuring a 3 m long area at its end that generally cannot be aerated and where sediments cannot be
evacuated. In addition, this effect is probably intensified by a deliberately reduced aeration due to energy savings covering only two-thirds of the aeratable grit chamber length.

The aeration rate, which has been used since the start of the MBR plant, was up to 1.5 m³/(m³ h); a very high value, which was to be evaluated critically. Thus, a stepwise reduction of the grit chamber aeration was investigated within this project. It was found that the grease removal was enhanced when a lower aeration rate is applied.

**Sampling point location**

Another important aspect addresses the capability of the sieve unit to transport the residues out of the sieve unit itself. If the cleaning of the sieve surface is not sufficiently working, pollutants might be concentrated in front of the sieve, the area where the sampling point (gₐ/gₐ (eff)/sieve in Figure 4) was located. To verify that, a new sampling point located 10 m upstream directly in the effluent channel of the grit chamber was used.

A comparison of the data obtained from the different sampling points is shown in Figure 5. The measurements were performed on 4 days between 8 a.m. and 4 p.m.

It is evident that a concentration gradient occurred in the transition section between grit chamber and sieve. This was observed particularly for the coarse SS fraction and less clearly for the fine SS fraction. The difference in the measured SSₕₜotal concentration reached a level of 100 to 150 mg/l and sometimes even more.

It is therefore important to highlight the importance of a proper sampling point location which strongly affects the relevance of the data obtained. In our case this leads to an underestimation of the grit chamber performance whereas the performance of the sieve was overestimated.

Therefore, the above-expressed assumption is confirmed, that the main sieve units show a high efficiency on retaining SS but a minor efficiency on removing the residues out of the wastewater flow. With respect to the sieve construction this might be caused by a relatively steep sieve installation within the wastewater channel. In addition, this sieve construction features no supporting devices to raise the residues to the top of the sieve. Therefore, they can more easily fall back again into the wastewater stream.
Precipitation in the inflow area

Another influence on the SS\textsubscript{total} balance was observed in the inflow area. In times of return flow a colour change (from yellow/orange to deep black) could be noticed due to a chemical reaction (Figure 6).

The presumable reason is a precipitation caused by sulphide content in the inflow stream resulting from long retention times (and therefore anaerobic zones) in the forcemain in combination with iron content in the return flow resulting from overdosing for the purpose of P-removal. In additional investigations it was found that the sulphide concentration in the inflow ranges from 6.7 to 13.2 mg/l which is considerably higher compared with typical municipal wastewater (1 to 5 mg/l). The return flow contained dissolved iron concentrations ranging from 22.2 to 65.0 mg/l.

Laboratory-scale experiments, in which raw wastewater and return flow were mixed at various ratios, confirmed that under such conditions iron sulphide precipitation occurs. At typical concentrations a SS increase of around 3% after 5 min (flow time from inlet works to the grit chamber) and of 15% after 1 h (usual retention time in the grit chamber under dry weather conditions) was determined. Thus, it can be concluded that the major part of the precipitation takes place within the grit chamber and in such a way influences the mass balances. With regard to these laboratory-scale results this SS production effect can be quantified with around 15% SS increase.
Based on these findings the following process modifications were made and three more measuring campaigns were conducted:

- Stepwise reduction of the grit chamber aeration from 1.5 m$^3$/(m$^3$ h) to 0.45 m$^3$/(m$^3$ h).
- New sampling point at grit chamber effluent; see Figure 5.
- Shortening of HRT; varying between 20 min and 50 min. (dwf).
- Time delayed sampling at the grit chamber effluent respecting the HRT.
- No return flow during measuring campaign.

With these new settings the best results were obtained at an aeration rate of 0.8 m$^3$/(m$^3$ h) and an average HRT (dwf) of 50 min. The corresponding removal of SS (including SS$_{\text{mineral, } >0.2 \text{ mm}}$) and grease are illustrated in Figure 7.

Figure 7 shows that about 53% removal of SS$_{\text{mineral, } >0.2 \text{ mm}}$ was measured. This removal was double that of the previous conditions with an aeration rate of 1.5 m$^3$/(m$^3$ h). Nevertheless, according to German Standard DIN 19569-2 (2002) for this parameter a minimum removal of 95% is required. The low removal rate is attributed to the low SS concentration. On average, the SS concentration was 78 mg/l in the grit chamber influent and 59 mg/l in the grit chamber effluent, out of which 20 mg/l fall upon SS$_{\text{mineral, } >0.2 \text{ mm}}$. It is well known that such low SS concentrations removal to an extent of 95% can hardly be achieved. From her investigation on sieve performance at various conditions, Hirschbeck (2010) concluded that the best grit removal rates in terms of percentage removal and also the fulfills of the requirements of the DIN Standard can only be accomplished with high grit influent concentrations. Thus, with the given raw water characteristics in Kaarst–Nordkanal no higher removal can be expected.

It has also to be considered, that the SS$_{\text{mineral, } >0.2 \text{ mm}}$ portion of SS$_{\text{total}}$ which amounts to 6% in the grit chamber influent, is comparatively low. This portion decreases down to 5% at the grit chamber effluent. SS$_{\text{mineral, } >0.2 \text{ mm}}$ portion of SS$_{\text{mineral}}$ amounts to 41% in the grit chamber influent and 34% at the grit chamber effluent.

Finally, it has to be noticed that with respect to organic grit a reduction of up to 40% occurs. It is generally known that excessive organic removal rates in the mechanical pre-treatment stage might have a negative impact on the subsequent biological process, especially the denitrification process. However, this was not the case and the legal requirements concerning nitrogen removal of the entire WWTP were met at all times.

The total grease load in the inflow grease trap area can be divided into 39% of emulsified grease and 61% of non-emulsified grease.

With reduced aeration capacity of 0.8 m$^3$/(m$^3$ h) and increased HRT (dwf) of 50 min the most satisfactory grease removal rates comparing all measuring campaigns were achieved. Emulsified grease was lowered by 20% and non-emulsified grease by 12%. The decrease of grease was 15%, which must be evaluated as an insufficient removal rate that causes problems for the downstream treatment units, especially the sieves. The fraction of non-emulsified grease tends to settle on the sieve surface and build a sticky layer. That supports the adhesion of SS at the inner sieve surface and can be seen as one of the reasons for the unsatisfactory SS removal.

The influences on the grit chamber performance can be summarised as illustrated in Figure 8.

**Comparison of sieve sizes**

Finally, one more important result of the project has to be mentioned addressing the performance of different sieve sizes. As
mentioned the mesh gap size of the rotating drum sieves was enlarged from 1 mm to 1.5 mm during the measuring campaign. This was due to the significantly increased personal and material efforts to clean the 1 mm sieve surfaces. It was not caused by an excessive biochemical oxygen demand removal.

This sieve change gave the opportunity to compare the removal capacity of the two types of sieves. The impact on MBR operation is visualised in Figure 9.

It is obvious that clogging and sludging of the membrane modules has largely increased after the sieve exchange (right). Accordingly the SS removal rates of the sieve decreased from 31 to 25% (see Table 2). The basic structure of the braid is built of hairs and fibres with accumulated sludge and these sections of the membrane surface are presumably hydraulically inactive.

It has to be noted that the earlier modification of the sieve type from slit geometry (0.5 mm) to mesh geometry (1 mm) resulted in a clearly improvement of removal of hairs and fibres and lower expenditures for the mechanical cleaning of the membrane modules (Drensla et al. 2009). However, the second modification from mesh gap size 1 to 1.5 mm seems to exceed a limit for efficient operation of hollow fibre membranes.

CONCLUSIONS

A major lesson learned from practical experience of MBR operation and as confirmed by this study is that MPT systems in MBRs are more sensitive and require high attention. Even if the MPT units are designed according to the currently established guidelines, this might not guarantee avoidance of membrane clogging problems.

The findings obtained can be concluded as follows:

- Parameter optimising within the grit removal/grease trap is of high importance to achieve optimal removal conditions
and to relieve the burden on subsequent MPT units. At the best test conditions 55% of \(SS_{\text{mineral}} \geq 0.2\,\text{mm}\) were removed. This is still less than the German DIN Standard stipulates (95%) but the given requirement is hard to meet considering the low \(SS_{\text{mineral}}\) concentrations at MBR Kaarst–Nordkanal.

- A low grease removal of only 15% was found which has severe impact on the process performance of the sieve unit. This refers, e.g., to the frequent starting of the emergency bypass and to higher efforts for sieve cleaning. Based on other experience, the authors consider poor grease removal a problem frequently occurring in wastewater treatment. However, standard wastewater treatment concepts usually do not include sieve units and therefore the impact on process operation is less critical whereas in MBR systems grease removal is of utmost importance.

- Investigating the performance of single MPT units, special attention should be paid on the appropriate location of sample points. Otherwise there is a high risk of data misinterpretation and overestimating or underestimating the single process capacities.

- A local particularity at MBR Kaarst–Nordkanal additionally hampers the grit chamber efficiency. It is a precipitation reaction of the sulphide in the inflow in combination with iron content in the return flow. This might be seen as a specific case but also illustrates that small effects which are disregarded in standard wastewater treatment can play a considerable role for pre-treatment in MBR operation.

- Previous findings at MBR Kaarst–Nordkanal (Frechen et al. 2008; Drensla et al. 2009) showed that two-dimensional sieves (mesh or hole geometry) are superior to one-dimensional sieves (slit geometry) in terms of removal of fibrous material and hairs even if the separation distance is enlarged from 0.5 to 1 mm. In this study it was shown that further enlargement of the sieve mesh gap >1 mm is not conducive and increasingly leads to clogging of the membrane modules.

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