PRETREATMENT REQUIREMENTS FOR MEMBRANE BIOREACTORS

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ABSTRACT

Adequate pretreatment including fine screening is essential to the stable, long-term operation of membrane bioreactors (MBR) used to treat municipal wastewater. The amount of screenings generated by a screen with 1-2 mm size openings ranges between 10-25 dry mg/L. The cost of fine screening represents less than 3% of the total investment cost for a MBR-based wastewater treatment facility. Case studies for three large MBR plants are presented illustrating that the membranes are free of trash and sludge accumulation after a cumulative 9 years of operation. Finally, concepts for mixed liquor screening are presented and the pros and cons of this approach are analyzed.

KEYWORDS

Membrane bioreactor, MBR, pretreatment, screening.

INTRODUCTION

The first generation of membrane bioreactors (MBR) in the 1970s and 80s were built with large diameter tubular membranes and were primarily used for small-scale industrial effluents containing little trash. Pretreatment to MBR first became an issue when hollow fibres and plate immersed membranes were introduced in the 90s for application to municipal wastewater. Today, municipal MBRS with capacities of up to 50,000 m³/d are in operation and much larger systems are in the construction, design or planning stages. Current research efforts aimed at reducing the cost of the technology will result in increasing membrane packing density and reducing membrane scouring aeration. This evolution makes it increasingly important to install adequate pretreatment to protect the membranes at the core of a MBR.

The potential negative impacts of poor pretreatment on the membranes themselves may include 1) build-up of trash, hair, lint and other fibrous materials, 2) increased risk of sludge accumulation and 3) damage to the membrane. Eventually, these impacts could result in a reduction of the hydraulic capacity of the plant and degradation of the effluent quality. In addition, trash in the mixed liquor can plug the coarse bubble aerators used to scour the membranes. These aerators are typically pipes with holes ranging in size between 5–10mm. A plugged aerator can deprive the membranes above it from scouring air and significantly decrease their efficiency.

Finally, trash that is not removed through pretreatment will build-up in the bioreactor because the membranes represent a complete barrier. From a mass balance point of view, the
concentration factor is equal to the ratio of sludge retention time (SRT) over hydraulic retention time (HRT); for example, with screenings in the MBR feed of 20 dry mg/L, SRT=15 days and HRT=6 hours, the trash content in the mixed liquor would build up to 1,200 mg/L. This represents a significant fraction of the mixed liquor that does not contribute to biological treatment, which thereby increases the required reactor volume.

SCREENINGS PRODUCTION

The best data available in the literature on MBR pretreatment are contained in an IWA published report of the pilot studies in Beverwijk, The Netherlands (van der Roest, 2002). The removal efficiency of different screens over several months is listed in Table 1. It is interesting to note that the 7.2mm bar screen removes very little solids, while the 0.5mm screens remove a large amount of paper fibres, in addition to hair and trash. Primary clarification ahead of fine screening actually removes the bulk of the screenings and would significantly reduce the solids loading to the fine screens. The authors concluded that 1.0mm-hole (not slots) screening is required to protect plate or hollow fibre immersed membranes.

Table 1 - Screenings contents of typical sewage with different screen configurations

<table>
<thead>
<tr>
<th>Feed</th>
<th>Screen</th>
<th>Screenings Dry (mg/L)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw WW</td>
<td>Bar screen (7.2mm slots)</td>
<td>&lt; 1.0</td>
<td>Very little removal</td>
</tr>
<tr>
<td>Raw WW</td>
<td>Vibrating screen (0.75mm holes)</td>
<td>14</td>
<td>Removal of essentially all trash (hair, seeds, etc)</td>
</tr>
<tr>
<td>Raw WW</td>
<td>Brush screen (0.75mm holes)</td>
<td>23</td>
<td>Removal of essentially all trash (hair, seeds, etc)</td>
</tr>
<tr>
<td>Raw WW</td>
<td>Rotary drum screen (0.5mm holes)</td>
<td>94</td>
<td>Significant removal of paper fibres that could be degraded in the MBR</td>
</tr>
<tr>
<td>Settled WW</td>
<td>Rotary drum screen (0.5mm holes)</td>
<td>2.8</td>
<td>Primary clarification removes most trash; the screen protects the membranes</td>
</tr>
</tbody>
</table>

In addition, observations made at six operating ZeeWeed® MBR’s in the United States has indicated that a large variability in wastewater screenings content can be encountered. The six sites, all using 2-mm fine screening, produced a range of 0.5 – 12.7 cubic feet of washed and compacted screenings per million gallons of wastewater (4 – 95 L / 1000 m³). Further analysis at two of these sites indicated generation of 13 and 20 dry mg/L of screenings, respectively, which is in the same range as the Beverwijk pilot data presented above.

ZeeWeed® MBR PRETREATMENT REQUIREMENTS

The pretreatment requirements for ZENON’s ZeeWeed® MBR are based on a robust and reliable multi-step approach. The minimum fine screening requirement is ≤ 2 mm mesh or punched-hole openings. The fine screening step itself may require pretreatment (e.g. coarse screening, grit/grease removal) for protection and optimal operation. The recommended pretreatment processes for the ZeeWeed® MBR include either of the following:
1. Coarse screening (≤ 6 mm) → grit/grease removal → ≤ 2 mm fine screening
2. Coarse screening (≤ 25 mm) → primary clarification → ≤ 2 mm fine screening

If flow equalization is incorporated into the design, it is preferred that it occurs prior to fine screening, in order to reduce the required size (and cost) of the fine screens associated with screening higher flows of wastewater.

The importance of pretreatment for MBR varies somewhat with the capacity of the plant. For small plants, where the cost of membranes relative to the overall MBR cost is lower, it is less critical to protect the membranes with a multi-step pretreatment process, as maximizing the lifespan of the membranes is less of a concern. However, for larger MBRs, where the cost of the membranes is a larger portion of the overall plant cost, the use of a well-designed, multi-step pretreatment process is an important factor in achieving the goal of maximizing membrane life and minimizing future membrane replacement costs.

**COST OF HEADWORKS SCREENING**

Table 2 shows that the cost of fine head-works screening (2mm) ranges between 0.10 –0.18 US$/MGD and represents less than 3% of the total investment cost for a wastewater treatment facility. The numbers were derived from a cost study published earlier (Côté et al, 2004). For the small plant, the costs are based on screening the raw sewage using rotary drum screens. For the large plant, pretreatment involves primary clarification followed by an in-channel drum screen.

**Table 2 - Typical membrane bioreactor costs**

<table>
<thead>
<tr>
<th>Cost Component</th>
<th>Capital Cost, US$/gpd (US$/m³/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant size and Average daily flow (Qave)</td>
<td></td>
</tr>
<tr>
<td>Total investment cost to end-user (including wastewater and sludge treatment; direct, indirect and land costs)</td>
<td>6.60 (3785 m³/d)</td>
</tr>
<tr>
<td>MBR portion (typical MBR supplier scope including membranes and ancillary equipment)</td>
<td>2.07 (548)</td>
</tr>
<tr>
<td>Fine head-works screening (installed equipment for 2 x Qave)</td>
<td>0.18 (48)</td>
</tr>
</tbody>
</table>
CASE STUDIES

Three plants that meet ZeeWeed® MBR pretreatment requirements listed above are described in Table 3.

Table 3 - Pretreatment case studies

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Brescia, Italy (Italy)</th>
<th>Traverse City, (MI), USA</th>
<th>Varsseveld, The Netherlands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date commissioned</td>
<td>Nov 2002</td>
<td>July 2004</td>
<td>December 2004</td>
</tr>
<tr>
<td>Wastewater</td>
<td>Sewage with large industrial contribution</td>
<td>Sewage</td>
<td>Combined sewage / rainwater with large industrial contribution</td>
</tr>
<tr>
<td>Feed flow rate (average, peak)</td>
<td>11 MGD (42,000 m³/d) constant; peaking handled by conventional plant</td>
<td>8.4 MGD (32,000 m³/d) average 16.8 MGD (64,000 m³/d) peak hourly</td>
<td>1.3 MGD (5,000 m³/d) average 4.7 MGD (18,000 m³/d) peak hourly</td>
</tr>
<tr>
<td>Biological treatment conditions</td>
<td>Nit/denit SRT=15-20d; HRT=7h; MLSS=8g/L</td>
<td>Nit/denit, bioP removal SRT=13d; HRT=6.4h; MLSS=8g/L</td>
<td>Nit/denit, bioP removal SRT=15-20d; HRT=7h; MLSS=8g/L</td>
</tr>
<tr>
<td>Pretreatment</td>
<td>30 mm coarse screen; aerated grit chamber; 2mm-hole, in-channel rotary drum screen with washer/compactor</td>
<td>6mm coarse screen; primary clarifiers; 2mm in-channel traveling-band screen</td>
<td>6mm coarse screen; aerated grit chamber; 0.8mm-hole pump-to screens (2 rotary drum screens; 2 brush screens)</td>
</tr>
<tr>
<td>Mixed liquor re-screening</td>
<td>Side-stream 0.5mm rotary drum screen</td>
<td>Not applicable</td>
<td>Mixed liquor periodically pumped back to headworks fine screens</td>
</tr>
<tr>
<td>Membrane filtration</td>
<td>8 membrane tanks with 4 filtration lines ZeeWeed® 500c</td>
<td>8 independent membrane tanks ZeeWeed® 500c</td>
<td>4 independent membrane tanks ZeeWeed® 500d</td>
</tr>
</tbody>
</table>

The Brescia MBR is a retrofit of one of three treatment trains of a conventional activated sludge plant. It was designed as a base-load plant with an essentially constant flow rate; peak flow to the plant is directed to the 2 conventional trains. Two steps of the pretreatment - 30mm coarse screen and an aerated grit chamber - are common to all trains. For the MBR, two in-channel rotary drum screens were added, each sized to handle the full flow. A 0.5mm rotary drum screen was installed to re-screen the mixed liquor but it has only been operated sporadically.

The Traverse City MBR is a retrofit of an existing conventional activated sludge plant. It has to treat the full flow and was designed for a peaking factor of 2.0. Because the sludge is digested...
anaerobically, primary clarification was used to minimize the organic loading to the MBR. The pretreatment thus consists of two 6mm coarse screens, primary clarifiers and 2mm in-channel traveling band screens.

The Varsseveld plant treats wastewater from a combined sewer system and is characterized by a high peaking factor of 3.6. The pretreatment was designed with a coarse screen (6mm), an aerated oil & grease and grit removal tank and a bank of four 0.8mm fine screens. The fine screens were designed for 2 times the rain weather flow to ensure sufficient capacity without bypass. The mixed liquor from the membrane tanks is periodically recycled to the fine screens during periods of low flow to remove any trash that may have formed or fallen in the tanks downstream of the screens.

All combined these 3 plants represent 9 years of real life experience of some of the largest and most successful MBRs built to date. Pictures of cassettes taken after the first year of operation in each of the plants are shown in Figure 3. These pictures represent the state of the membranes as they were pulled out of the tanks, without any cleaning or sludge removal. All membranes and cassette aerators are free of trash and sludge.

Figure 1 - Membrane cassettes from operating plants (out of the tank with no cleaning)
MIXED LIQUOR SCREENING

Mixed liquor screening has also been explored as an alternative to raw sewage screening. Screening the mixed liquor offers the benefit of removing any contamination downstream of the head-works (such as vegetation debris carried by wind and re-roping of hair as a result of mixing in the aeration tank). A benefit of this approach is that any screenings removed from the mixed liquor are “cleaner” as they have been subjected to biological treatment. However, because of the higher suspended solids contents, loading rates when screening mixed liquor can be lower than when screening raw sewage.

Two options for mixed liquor screening are considered: side-stream screening and full return activated sludge (RAS) flow screening. Both are illustrated in Figure 2, along with an indication of the flows involved.

With side-stream screening, a constant and small flow is taken from the aeration tank, screened and put back into the aeration tank (Figure 2a) to continuously remove trash from the system. Based on a mass balance, the equilibrium concentration of trash in the bioreactor \(X_b\) is related to the concentration of trash in the influent downstream of head-works screens \(X_f\) as follows:

\[
X_b = \frac{SRT}{\frac{ySRT}{HRT}} \cdot X_f
\]

where \(y\) is the fraction of the influent flow processed through the side-stream screen. Carrying on with the example given in the introduction \((X_f = 20 \text{ mg/L}; \ SRT = 15 \text{d}; \ HRT = 6 \text{h})\) and assuming that \(y = 0.25\), the trash content in the mixed liquor \(X_b\) would equilibrate to 75 mg/L. This represents a 94% reduction as compared to the reference case without side-stream screening, for a screen that is sized for only 25% of the influent average flow rate. A similar effect can be achieved by recirculating a fraction of the mixed liquor to the headworks screen during periods of low flow. While this approach significantly reduces the amount of trash in the bioreactor, it still allows a residual amount to flow through the membrane tank and be in contact with the membranes.

![Figure 2 - Two options for the removal of trash from mixed liquor](image)

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With full RAS flow screening, the fine screens are located between the aeration tank and the membrane tanks (Figure 2b). The screens have to be sized for the full recirculation flow, typically 3-5 times Q; however, this flow typically remains constant as the influent flow changes. This is the only option that allows positive protection of the membranes from trash present in the influent (resulting from head-works screens by-pass or overflow) and from contamination downstream of the head-works. With this option, it is possible to relax requirements for head-works screening as the trash remains in the aeration tank. Trash can either be removed with the waste activated sludge, avoiding any screenings handling, or continuously extracted with sidestream screening.

**IMMERSED SCREEN**

A new concept for continuous mixed liquor screening is illustrated in Figure 3. It involves building an immersed screen at the entrance of the membrane tank. The screen is static (no moving parts), intersects the entire mixed liquor flow from the biological tanks and does not allow by-pass or overflow to the membrane section downstream.

The required immersed screen area depends on the surface area of membranes in the tank. For small systems, a flat screen panel covering the cross section of the tank is sufficient. For larger systems, options to increase surface area include use of corrugated flat screens or cylindrical screens.

![Figure 3 - Concept for a membrane tank immersed screen](image)

The mixed liquor flows through the immersed screen under a small head difference that develops between the up-screen and membrane sections, typically 4-10 inches (10-25 cm). The up-screen section is gently air-scoured to prevent blinding. Periodically (every 5-20 min), the scouring air flow rate is increased suddenly for a short period of time (10-30 sec) to a level that significantly reduces the density in the up-screen section, causing a backwash of the screen, airlifting the accumulated trash and overflowing of the reject into biological tanks (directly or through the...
return activated sludge channel). This can be done without interrupting the mixed liquor flow from the biological tanks.

A pilot unit was built to validate the immersed screen concept. It consisted of a small tank 38” long x 16” wide x 79” high (96.5 cm x 40 cm x 200 cm) similar to Figure 3 equipped with a flat screen of 5.4 ft² (0.5 m²) defining a up-screen section with a footprint of 4.3” x 16” (10.9 cm x 40 cm) and a membrane section of 16” x 34.2” (40 cm x 87 cm). The pilot was operated without membranes to test the operating parameters of the screen.

The pilot was fed with the mixed liquor from an existing MBR plant (Creemore, Ontario) equipped with a 3 mm head-works screen. The screenings in the mixed liquor were characterized with a stack of sieves as described in Table 4. A negligible amount of screenings was retained on the 2.8 mm sieve but a significant amount of 39 dry mg/L (cumulative) was collected on the 1 mm sieve. As mentioned above, going down to 0.5 mm resulted in the retention of a large amount of paper fibres for a total of 141 dry mg/L.

**Table 4 - Sieve analysis of the Creemore MBR mixed liquor**

<table>
<thead>
<tr>
<th>Sieve Opening (mm)</th>
<th>Screenings retained (dry mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7</td>
<td>0.1</td>
</tr>
<tr>
<td>2.8</td>
<td>0.5</td>
</tr>
<tr>
<td>2.0</td>
<td>4.2</td>
</tr>
<tr>
<td>1.0</td>
<td>34.2</td>
</tr>
<tr>
<td>0.5</td>
<td>102</td>
</tr>
<tr>
<td><strong>Cumulative</strong></td>
<td><strong>141</strong></td>
</tr>
</tbody>
</table>

The results of a series of experiments with the immersed screen pilot are summarized in Figure 4. All experiments were run at an instantaneous loading rate of 3.7 gpm/ft² (9.0 m/h), with a terminal head-loss (backwash trigger) of 8” (20 cm). A continuous air flow rate of between 2.3 – 4.7 scfm/ft² of footprint (42-86 Nm³/m²/h) was applied in the up-screen compartment during production. Under these conditions, the interval between backwashes was recorded (time required to reach terminal head-loss). A backwash consisted of increasing the airflow rate to 23.2 scfm/ft² (424 Nm³/m²/h) for 10 seconds. During a backwash, the water level in the membrane section decreased by a few inches even though the mixed liquor feed flow rate was not interrupted; the backwash reject overflowed over a weir located 12” inches (30.5 cm) above the normal operating level in the membrane section.

Three different wire mesh screens were evaluated, with openings of 0.5 mm, 0.75 mm and 1.0 mm; the removal efficiency for these three sizes were 98%, 65% and 57% respectively of the cumulative 141 dry mg/L. As shown in Figure 4, the 0.75 mm and 1.0 mm screen gave similar results, with intervals between backwashes of 8 – 20 min, increasing with scouring airflow rate. The 0.5 mm screen led to much lower intervals due to the retention of paper fibres as described above.
These results indicate that it would be possible to integrate an immersed screen into a MBR membrane tank with little additional equipment required. The immersed screen contains no moving parts and can be backwashed using an available air source (either the membrane scouring air or the process air). The interval between backwashes is of the same general duration as the membrane production cycle (i.e. interval between relaxations or backwashes) and the two operations could be synchronized.

![Graph](image)

**Figure 4 - Immersed screen piloting results on the Creemore MBR mixed liquor**

**CONCLUSION**

Membrane bioreactors for municipal applications require pretreatment to protect the membranes at the core of the process. Proper pretreatment eliminates the risk of 1) trash, hair and sludge accumulation in the membranes, 2) plugging of the membrane aerators and 3) degradation of the effluent quality that can occur if the membranes are damaged.

Trash that can be detrimental to membrane operation can be removed by a 1-2mm wire mesh or true-hole screen. The amount of screenings generated is typically in the range of 10-25 dry mg/L of wastewater. Any trash that by-passes or goes through the screen will be concentrated in the bioreactor by a factor of 50 to 100 (i.e. by the ratio of SRT/HRT).
ZENON’s recommendation for MBR pretreatment is a multi-step approach involving either 1) coarse screening (≤ 6 mm), grit/grease removal and ≤ 2 mm fine screening, or 2) coarse screening (≤ 25 mm), primary clarification and ≤ 2 mm fine screening.

The cost of the fine screening step represents only 3% of the total capital cost of a MBR plant to the end-user. It is an investment worth making to protect the membranes at the core of a MBR and maximize their life.

Three plants built and operated following ZENON’s pretreatment recommendations were presented. All combined, they represent 9 years of real life experience of some of the largest and most successful MBRs built to date. Pictures of cassettes taken after the first year of operation in each of the plants show that the membranes and the cassette aerators are free of trash and sludge.

Mixed liquor screening is a complement or alternative to head-works screening currently in the development stage; it offers the following potential benefits: 1) better protection of the membranes from trash contamination downstream of the head-works, 2) easier-to-handle screenings that have been “cleaned” biologically and 3) lower costs.

A new immersed screen that could be built at the front end of the membrane tank was evaluated at pilot scale. Initial results indicate that it could be used to continuously screen the mixed liquor and cleaned with a periodic backwash triggered by a short burst of aeration.

REFERENCES


