The importance of measuring the sludge filterability at an MBR – Introduction of a new method

C. Thiemig

ABSTRACT

Sludge properties have a strong impact on the operational aspects of membrane bioreactors (MBRs). Poor sludge properties cause stronger membrane fouling and reduce the filtration performance of MBRs. Up to now there is no general method used to measure the fouling or filtration relevant sludge properties in MBRs. The aim of this work was to develop a simple but reliable method to supply operators a tool to monitor the important sludge properties for their application and to compare this method with existing techniques. Through extensive research a new method called the sludge filtration index (SFI) has been developed to indicate the appropriate sludge parameters for MBR systems in a cheap and easy manner. The SFI can be measured with simple laboratory equipment and offers operators a powerful tool to monitor the conditions of their sludge, independent of the membrane conditions.

Key words | filter test, filterability, fouling, MBR, SFI, sludge

INTRODUCTION

There are two processes of major importance for the operation performance of a membrane bioreactor (MBR): fouling and the relatively reversible formation of a cake layer during filtration. It is well-known that fouling processes correlate with the concentration of the extracellular polymeric substances (EPSs) (e.g. Chang & Lee 1998; Rosenberger & Kraume 2002; Rosenberger 2003). EPSs are omnipresent and, consequently, fouling is unavoidable and under normal operation conditions is a slow-going but persistent process.

In contrast, fouling cake layer formation (CLF) is a short-time process. The cake layer can normally be removed from the membrane surface by the shear forces introduced by the crossflow aeration. CLF depends mainly on the specific flux and the crossflow intensity. Additionally, various sludge properties affect the extent to which the cake layer forms.

Extended periods of high specific flux with an increased CLF can cause a cake layer that can no longer be removed by the crossflow. During such conditions parts of the cake layer are compacted by high transmembrane pressures (TMP) causing a strong adhesion to the membrane surface. This special type of fouling can sometimes be removed by a permeate backwash which is possible with some module systems. If the compacted cake layer is too thick and dense then chemical cleaning is an option to remove the remaining fouling layer. Another possibility to clean the membrane surface area is the so called ‘Mechanical Cleaning Process – MCP’ reported in Siembida et al. (2010). This methodology utilizes plastic particles, which are added to the activated sludge. The particles clean the membranes by their interaction with the cake layer.

There is no distinct border between normal fouling, reversible CLF and the compacted CLF. In fact, there is a fluent passage between all described effects. Both, membrane fouling and (compacted) CLF have a strong impact on the operation of an MBR by their correlation to the TMP. The TMP in combination with the flux is the only indicator for the operator to judge the membrane conditions. Additional information about the filtration- and fouling-relevant sludge parameters is helpful to discover the reasons for increasing TMP. As a result, different methods, such as the capillary suction time (CST) and advanced test cells have been used to measure the sludge filterability, but none has been established yet for a frequent measurement on MBRs.

The present paper gives an overview on the existing methods and introduces the newly developed sludge systems.
filtration index (SFI). The SFI is easy to measure with simple laboratory equipment on site by the plant operators. The development of the SFI will be described in detail. The validation of this method by long term monitoring programs at different municipal MBRs showed a higher reproducibility compared with CST or another simple filtration test.

Existing methods to measure the sludge filterability

CST

The CST is a frequently used method to measure the filtration properties of activated sludge in MBRs. Originally this method is applied to determine the dewatering properties of sludge in the field of sludge processing (e.g. to determine the optimum conditioner dosage while dewatering by centrifuge etc.). The principle of CST is based on the effects of capillary flow in a porous filter paper originally used for chromatography. A small sludge sample is dewatered through the filter paper. The extraction time defines the CST value. The advantage of using the CST for measuring the sludge filterability in MBR is the existing long time experience by measuring this parameter during sludge dewatering processes. Some authors also found a correlation between CST and the permeability in the MBR (e.g. De la Torre et al. 2008) which makes this methodology obviously suitable to monitor the sludge properties in MBRs. However, there are no restrictions for the type of filter paper even if there is a technical norm describing the materials and methods for measuring the CST (DIN EN 14701-1 2006). Also there are no regulations to relate the results to the MLSS concentration or the sample temperature to the results, although both aspects affect the results strongly.

Filter test

Another often used method is a very simple filter test (FT) which was introduced by a large Japanese MBR module manufacturer in 1998 (Nurishi et al. 1998). By this method a 50 ml sludge sample is filtered through a folded filter paper in a small funnel. The amount of filtrate after 5 min defines the filtration parameter.

Other test cells

There are a couple of other methods described in various publications. Rosenberger used a cross-flow test cell with an active membrane area of 88 cm² (flat sheet membrane) operated with a TMP of 1 bar (Rosenberger 2003). Evenblij used a similar system utilizing a hollow fiber membrane with a total membrane area of 240 cm² (Evenblij 2006). Wett is measuring the sludge filterability in a stirred test cell with a membrane area of about 29 cm² (Wett 2005). Unfortunately all these methods need relatively complicated equipment, are difficult in operation and the measurement takes a long time, which makes them all unattractive for a daily on-site use.

MATERIALS AND METHODS

Development of a new method

The new method should be easily conducted on site with commonly used equipment and produce both reliable and reproducible data describing the membrane filtration relevant to the sludge properties. Both commonly used methods (CST and FT) use a very small sludge amount which affects the variation and quality of results significantly. As a result the new method was developed using a larger sludge sample of 500 ml. The effect of MBR’s typical crossflow aeration, which limits the CLF during filtration, was reproduced by a stirring device with a slow rotational speed of 40 rpm. The stirring device agitates the sample during gravity filtration induced by a Buchner funnel which holds a commonly used filter paper (Macherey-Nagel MN 85/70). Table 1 shows the equipment and describes the procedure. A detailed description of the method development and validation can be obtained in Thiemig (2011).

Execution:

- Take a 1 L sludge sample of the MBR shortly before measurement.
- Insert the filter paper (smooth side up) into the funnel.
- Place the empty 250 ml measuring cylinder under the funnel.
- Clamp blade agitator at a height of 0.5 cm over the filter paper. Activate the drive and set to 40 min⁻¹ revolutions (according to the usual cross-flow velocity).
- Mix the sludge sample well and temper a 500 ml sample in a water bath to 20 °C.
- Measure the amount of suspended solids SS of the remaining sludge sample.
- Quickly pour the 500 ml sample into the filter.
- Activate the stopwatch when the filter volume reaches the 100 ml mark.
- Stop the watch when the filter volume reaches the 150 ml mark.
The specific value of the SFI is calculated from the measured time $\Delta t$ [sec] with respect to the concentration of suspended solids $SS$ [%].

$$SFI = \frac{\Delta t}{SS \%SS}$$

Method validation

The validation of the newly developed method was done in two steps. The first step was a comparative measurement period with sludge samples from four different municipal MBRs (two large scale MBRs, two pilot scale MBRs). From each plant, three samples were taken at different times. Every single sample was measured six times with each method (CST, FT, SFI) and the coefficient of variation (COV) was calculated from the six relatively different results to indicate the reproducibility of each method. In total, 216 measurements were done to produce a statistically evaluable database.

A high reproducibility of a measurement procedure (corresponding to a low COV) does not necessarily define a method which describes the dedicated properties of a sample. This aspect was examined during the second step of validation with a long time monitoring program for 24 months at two different large scale MBRs. Weekly samples were measured with CST and SFI to compare both methods and to monitor seasonal changes of sludge filterability.

RESULTS AND DISCUSSION

Statistical comparison of three methods

The highest reproducibility of a method is represented by a minimum variation of the six measurements from each identical sample. The results of the statistical validation of all three compared methods broken down to the four monitored MBRs are shown in Figure 1. All MBRs showed similar COV in each method which indicates a comparative database. The average COV of the SFI (2.5) was significantly lower than the variations of the filter test (6.8) and the CST (6.0). This confirms the high reproducibility of the SFI procedure. The higher coefficients of variation of FT and CST are likely caused by the smaller sludge sample.

Table 1 | Setup and materials for measuring the SFI

<table>
<thead>
<tr>
<th>Setup:</th>
<th>Materials:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Drive: Motor output 105/30 W, Adjustable revolutions per minute.</td>
<td>1. 1 Drive: Motor output 105/30 W, Adjustable revolutions per minute.</td>
</tr>
<tr>
<td>2. 1 Buchner funnel for filters with Ø 150 mm, Volume 1,250 ml, porcelain, white glazed.</td>
<td>2. 1 Buchner funnel for filters with Ø 150 mm, Volume 1,250 ml, porcelain, white glazed.</td>
</tr>
<tr>
<td>3. 1 Measuring cylinder, Volume 1,000 ml.</td>
<td>3. 1 Measuring cylinder, Volume 1,000 ml.</td>
</tr>
<tr>
<td>4. 1 Measuring cylinder, Volume 250 ml.</td>
<td>4. 1 Measuring cylinder, Volume 250 ml.</td>
</tr>
<tr>
<td>5. 1 Blade agitator: Rod (Ø 7 mm, Height 400 mm), Blade (Height 10 mm, Width 90 mm, Sheet thickness approx. 1 mm).</td>
<td>5. 1 Blade agitator: Rod (Ø 7 mm, Height 400 mm), Blade (Height 10 mm, Width 90 mm, Sheet thickness approx. 1 mm).</td>
</tr>
<tr>
<td>6. 1 Stand, Height 1 m.</td>
<td>6. 1 Stand, Height 1 m.</td>
</tr>
<tr>
<td>7. 3 Stanchions to clamp the drive and the Buchner funnel (with the Ø 140 mm circular end above; as pliers with adjustable end below).</td>
<td>7. 3 Stanchions to clamp the drive and the Buchner funnel (with the Ø 140 mm circular end above; as pliers with adjustable end below).</td>
</tr>
<tr>
<td>9. Filter paper: Ø 150 mm; 0.6 μm; MN 85/70.</td>
<td>9. Filter paper: Ø 150 mm; 0.6 μm; MN 85/70.</td>
</tr>
</tbody>
</table>
Long-time monitoring program

Figure 2 displays the seasonal changes of sludge filterability at the MBR Xanten-Vynen in Germany. SFI and CST showed very similar tendencies. During the winter season both parameters disclosed a poor filterability of the activated sludge. A correlation of filterability with the water temperature was obvious. The graph shown in Figure 3 verifies this assumption. The plotted data were derived from a database which compared the monthly average wastewater temperature and the SFI at the end of each month. It should be emphasized that all samples were tempered to a temperature of 20°C before each measurement. Hence, the sludge viscosity is not responsible for the seasonal variation of SFI and CST.

(Rosenberger 2005) and (Wett 2005) distinguish in their researches between the soluble and bound EPS. According to their experiences, the soluble EPS (soluble microbial
products (SMP) are mainly relevant for sludge filterability and membrane fouling. The bound EPSs play a minor role in these aspects. Figure 4 shows data from a municipal MBR treating an average wastewater flow of 290 m$^3$/d. The SMP were quantified via the TOC of the liquid phase after centrifugation. The amount of bound EPS was also measured, via TOC after resolving the bound EPS from the residual particulate matter, by adding an exchange resin and after a resolving time of 30 min under constant stirring.

Within a limited number of measurements a good correlation between SFI and SMP was found (Figure 4, left). Against this the correlation between SFI and bound EPS was poor (Figure 4, right). Both results confirm the experiences of Rosenberger and Wett. Hence it can be assumed that the SFI is a proper method to measure the filterability- and fouling-relevant properties of activated MBR sludge.

Finally a direct correlation between the SFI and the operational parameters of an MBR were investigated in a pilot scale MBR (2 m$^2$ flat sheet membranes) with real municipal wastewater under fixed conditions (constant flux settings and crossflow aeration). Peak flux tests under different sludge properties (monitored via the SFI) showed explicit results. Lower SFI values correlated with a stronger increase of the TMP.

It should, however, be mentioned that such correlations cannot be transferred in a general way as every system is different in various aspects. The biggest impact is the module design, especially the aeration system. A more efficient air crossflow lowers the effects of poor sludge properties. Additionally, the history of the membrane is also important, e.g. the fouling conditions during the measurements.

**CONCLUSIONS AND OUTLOOK**

A new method to measure the fouling relevant sludge properties has been developed and validated. The SFI is simple to conduct with common laboratory equipment and could become a helpful tool to monitor the seasonal changes of sludge filterability. It could be shown that temperature changes also affect the sludge filterability not only by the change of viscosity. A correlation between SFI and the soluble EPS, which have a major impact on membrane fouling, was also shown.

Meanwhile the SFI is measured at a number of different MBR plants. The increasing database provides the opportunity for a quantitative evaluation and comparison of the sludge filterability of MBRs under different operating conditions. Consequently, it becomes possible to modify sensitive operating parameters with the target of maximizing the filterability. On the other hand it is possible to operate a MBR under energy optimizing preferences, e.g. by operating the modules with higher flux or to minimize the high energy consuming crossflow aeration if the sludge conditions are good. Finally, the experience from the growing database can be implemented for future design guidelines for MBR.

**REFERENCES**


De la Torre, T., Lesjean, B., Drewa, A. & Kraume, M. 2008 Monitoring of transparent exopolymer particles (TEP) in a membrane bioreactor (MBR) and correlation with other...


First received 28 November 2011; accepted in revised form 21 February 2012