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An easy numerical evaluation of the DM growth in Self-Forming Dynamic Membrane Bioreactors (SFD MBR) for Wastewater Treatment

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Abstract. In the last years, self-forming dynamic membranes (SFD MBR) revealed as one of the most innovative technological solutions for wastewater treatment. In these systems, filtration takes place through a cake layer (Dynamic Membrane, DM) supported by a 10-200 µm filter mesh.
Filtration efficiency may decrease when the DM becomes too thick or its composition changes, and this can be measured under constant flux through the increase of TMP (TransMembrane Pressure).
In this study, three different DM maintenance strategies have been adopted to limit the loss of performance caused by excessive cake layer growth. A 4h filtration cycle was applied ending with a filtration break of 11' with different mesh cleaning strategies. The cake growth on the support mesh was analyzed evaluating the TMP increase rate. TMP peaks in the range 20-200 mbar were observed during the 4h filtration cycles. These data were interpreted with second order interpolations and linear trends.
Here, the slopes of the trend lines are used to evaluate the performance of the different DM maintenance strategies considered. These lines provide a simplified representation of the speed at which the pressure of 200 mbar is reached, once the DM thickness starts to increase (lower TMP instability threshold of 20 mbar). These slopes allow to estimate cake layer accumulation: the lower the slope value, the longer the time to reach the critical TMP value.

Keywords: SFD MBR; wastewater treatment; cake layer; TMP increase rate

1. Introduction

In recent years, the Self-Forming Dynamic Membrane Bioreactor (SFD MBR) were proposed to overcome the limits of the conventional MBR. In these systems, filtration nets are used as filtering supports to favor the spontaneous accumulation of a biological layer (cake, or dynamic membrane DM), which becomes the main filtration medium [1]. SFD MBR allows to achieve some advantages, such as high effluent productivity, low energy requirement, cheap support materials (e.g., nylon or polyethylene mesh) [2].

In the case of MBR and micro-ultrafiltration processes, the comprehension of fouling mechanisms is critical for the steady operation, and these have been thoroughly investigated [3, 4]. In the SFD MBR, the optimization of operation requires accurate control of the biological layers that tend to accumulate on the filtration support. As a matter of fact, excessive accumulation and consequent thick cake layers, as well as the insufficient build-up of DM determine the decrease of the system's performance, respectively causing the rapid TMP increase, which limits filtration, or low-quality effluents, and may result in reduction of Mixed Liquor Suspended Solids (MLSS) [5].

In this work, a SFD MBR for treating municipal wastewater was set-up at the laboratory scale. A comparison between three different strategies for mesh cleaning was made to investigate the increase rate of the TMP, which reveals the cake growth on the support mesh. TMP peaks in the range 20-200 mbar observed during 4h filtration cycles (229 minutes of filtration, 11 minutes of break) were interpreted with second order interpolations and linear trends. The slopes of the trend lines are used to compare the performance of the different DM maintenance strategies considered.

2. Materials and methods

A laboratory scale plant was set-up as shown in Figure 1. A completely mixed and aerated bioreactor had 14 L operating volume. A nylon mesh with a pore size of 50 µm (Nitex©, Sefar AG, Heiden Switzerland) was used as support material for the growth of DM. The total filtering surface was about 0.0144 m^2. The effluent was extracted with a peristaltic pump (NIKE NK M Pro, INJECTA s.r.l., Rieti, Italy), and all the experiments were run with a net flowrate of about 0.52 L h^{-1}. The plant feed and effluent extraction were synchronized by maintaining constant the reactor operating volume through a level control. Sludge mixing was provided by an air pump with an average flowrate of 4 L min^{-1} (M2K3, Schego, Germany) equipped with a fine-bubble diffuser placed at the bottom of the reactor, which also ensured a concentration of dissolved oxygen (DO) in the range 2 – 4 $mgO_2\ L^{-1}$ for biological oxidation processes. The sludge retention time (SRT) of the biological system was always maintained at 15 days.

Continuous washing of the filtering surfaces with air through bubbles diffusers placed immediately under the meshes to limit the accumulation of cake and the TMP tendency to increase was adopted as benchmark (called P1). This was compared for effectiveness with two different approaches. The first consisted of timed periodic backwashing of the meshes with a limited volume of the permeate produced (P2). The second one involved the cyclic supply of a massive air load for cleaning the meshes (P3), with a much larger volume and pressure with respect to the fine bubble diffusers used for the continuous air scouring in the benchmark configuration. Process effectiveness under the different testing conditions was evaluated in terms of effluent quality (turbidity and other physical and chemical parameters) and sustainability (pressure increase rates and frequency of on-site manual cleaning of the supports).

The TMP was monitored in continuous through a pressure transducer (VAL.CO s.r.l., S. Ilario di Nerviano, Italy) connected to a datalogger (Sysman Progetti e Servizi s.r.l., Italy), and pressure data were recorded every 5 minutes. When the TMP values exceeded about 200 mbar (negative pressure), the modules were removed from the reactor and manually cleaned through tap water jet rinsing of the filtering surface.

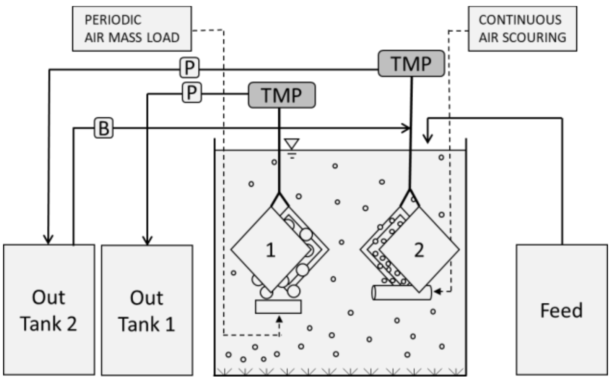

Figure 1. Scheme of the SFD MBR experimental set-up.

The influent wastewater and the effluent were accumulated, stored at 4 °C, and sampled weekly for the analysis of the main chemical and physical parameters. All analyses and determinations were performed according to Standard Methods [6].

In process performance monitoring, the DM was considered to grow beyond equilibrium conditions when the TMP reached values above 20 mbar (negative pressure), and this value was chosen as the starting point of the TMP increase (sludge cake growth phase).

The rate of increase in TMP over time was calculated from the slopes of the respective trend lines. This approach was adopted to obtain a simple parameter (slope) that could be used to compare DM performance and maintenance strategies. These lines provide a simplified representation of the speed at which the pressure of 200 mbar has been reached once instability has been ascertained, i.e. after the conventional threshold of 20 mbar has been exceeded. Simply calculating these slopes is an easy way to evaluate cake layer accumulation: the lower the slope value, the longer the time to reach the critical TMP value.

3. Results and discussion

The formation of DM is a crucial step for the operation of SFD MBR. The main parameters of the produced effluents in terms of removals are shown in Table 1.

Table 1. Removals of main conventional parameters.

Parameter	outP1 (%)	outP2 (%)	outP3 (%)
CODrem	95.3%	90.6%	95.1%
TSSrem	97.7%	95.2%	98.0%
TNrem	27.6%	21.2%	27.6%
NH_4^+rem	99.8%	100.0%	99.6%

All the COD removal efficiencies were in the range 90.6 – 95.3%, while TSS removals were almost complete. About nitrogen compounds, ammonium was completely removed, while a partial nitrogen removal was achieved.

Figure 2 shows an example of TMP increase for every adopted maintenance strategy in terms of maximum TMP values reached at the end of every 4 h cycle, within the range 20-200 mbar (absolute values). The TMP increase rate is represented by the slopes of the respective trend lines (straight lines). TMP increase rates, in terms of longer or shorter timeframes between the start of the system's instability (20 mbar, the start of TMP increase) and the high threshold of 200 mbar, when the system was starting to lose productivity [7], resulted to be dependent on the different DM maintenance strategies. Second-degree polynomial functions of the same selected datasets (dashed lines) are also shown, which represent the best fitting functions of the series. The different tests showed different dataset trends, corresponding to different polynomial functions, respectively.

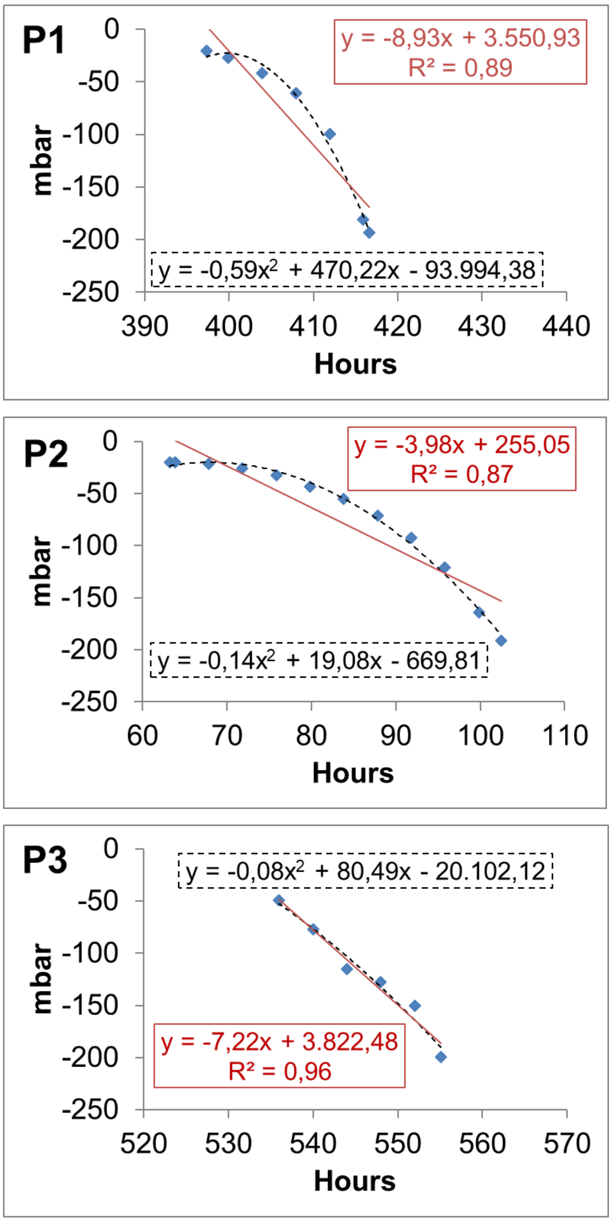

Figure 2. For every maintenance strategy (P1, P2, P3), an example of second-degree polynomial function (dashed line) and trend line (straight line) of TMP values is represented considering the end of each 4h cycle in the range 20-200 mbar.

The effectiveness over time of the cyclic temporized DM maintenance strategy adopted, i.e. the duration of the DM equilibrium conditions, is indirectly represented by the frequency of manual cleaning. The lower the frequency, the higher the effectiveness, because a longer equilibrium of the system is obtained, i.e. suction pressure values below 20 mbar for extended periods without the start-up of progressive TMP increase.

The rate of TMP increase and the frequency of manual module cleaning were considered the main operational characteristics of the different cyclic temporized module cleaning strategies. In figure 3, the cleaning frequencies and TMP increase rates mean values are shown.

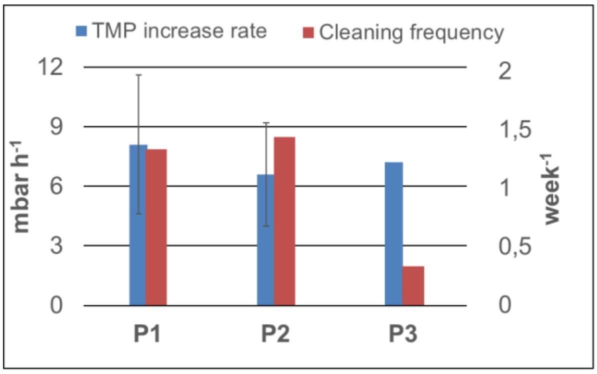

Figure 3. Average TMP increase rates and manual cleaning frequencies.

The average TMP increase rate for each test represents the average slope of the (negative) pressure increase lines, as described above.

4. Conclusions

The high-quality effluents of SFD MBR, an interesting and promising wastewater treatment technology, can easily comply with standards for reuse, well-fitting the context of circular economy and environmental sustainability.

Filtration efficiency can decrease when the DM becomes too thick or its composition changes, and this can be measured at constant flow by increasing the TMP.

The slopes of the trend lines of maximum TMP values represent an easy way to compare the performance of the different DM maintenance strategies. Indeed, these slopes allow for a rapid evaluation of the cake layer accumulation: the lower the slope value, the longer it took to reach the critical TMP value, and the more efficient the maintenance strategy adopted.

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