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Detecting membrane fouling occurrences in a full-scale membrane bioreactor with principal component analysis

L. De Temmerman[*,**], W. Naessens[**], T. Maere[**], S. Marsili-Libelli[***], K. Villez[****], H. Temmink[*,*****], I. Nopens[**]

[*]Wetsus Centre of Excellence for Sustainable Water Technology, P.O. Box 1113, 8900 CC Leeuwarden, The Netherlands

[**]BIOMATH, Department of Mathematical Modelling, Statistics and Bioinformatics, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium

[***]Department of Information Technology, University of Florence, Via S. Marta 3, 50139 Florence, Italy

[****]Process engineering, Eawag, Uberlandstrasse 133, Postfach 611, 8600 Dübendorf, Switzerland

[*****]Sub-department of Environmental Technology, Wageningen University, P.O. Box 17, 6700 AA Wageningen, The Netherlands

Abstract: The technique of principal component analysis (PCA), previously successfully applied to a lab scale MBR, has now been applied to high-frequency transmembrane pressure (TMP) data from a full-scale membrane bioreactor (MBR) for wastewater treatment. The focus hereby is to analyze the membrane's fouling behaviour over an 8-month period. In addition to TMP, logbook, temperature and flux data were included to hypothesise the underlying causes for the observed membrane fouling. PCA was able to separate between irreversible and reversible fouling events and thus describe the actual state of the membrane, while the additional data revealed the importance of flux and temperature in relation to deteriorating sludge filterability and increasing filtration resistance.

Keywords: reversible fouling, irreversible fouling, correlation, wastewater treatment, data mining

Introduction

Membrane fouling is an undesired but unavoidable process in full-scale membrane bioreactor (MBR) plants for wastewater treatment. As advised by membrane producers, a fixed, experience-derived operational scheme is usually implemented at full-scale including membrane aeration, backwash and chemical cleaning in conjunction with routine analyses of membrane permeability to safeguard operation. However, such fixed schemes are never optimal, ignore the dynamic nature of fouling and lack the flexibility to cope with changing influent, biological and membrane conditions. Moreover, they are usually very conservative. The resulting waste of energy, permeate, chemicals and membrane life-time provides significant potential for improving cost-efficiency based on dynamic and online control (Maere et al., 2012).

Principal component analysis (PCA) is a relatively straightforward data mining technique to organize and explore large data sets. Maere et al. (2012) demonstrated its use to visualize trends in on-line membrane filtration data, based on a historical lab-scale TMP data set and described its potential to monitor the membrane state and control the fouling process. In the current contribution, we apply and evaluate PCA for the first time to a full-scale MBR historical data set.

Material and methods

At the full-scale sidestream MBR ”De drie Ambachten” (Terneuzen, The Netherlands), TMP measurements were collected at an interval of 1 second for the period August 2011 - March 2012, in addition to hourly average values for flux, daily average values for temperature and detailed operational logbook data. The vast amount of high frequency TMP measurements was reduced into three parameters for each membrane filtration cycle (duration of 1 cycle is 455s). These parameters, i.e. filtration pressure peak (+ΔP), backwash pressure peak (-ΔP) and the TMP slope during filtration (S), were chosen based on expert knowledge as in Maere et al. (2012) (Fig. 1.1). In contrast to the latter study, the TMP profiles in this study, however, do not clearly follow first order kinetics at the start of a filtration cycle. Therefore, the two first order parameters *a* and *b* describing the pressure build-up after backwash were omitted in the current analysis. By adding the respective values for flux (J) and temperature (T) per cycle, a PCA based on 5 parameters was performed.

Results and discussion

The evolution of the five selected parameters (+ΔP, -ΔP, S, T, J) per filtration cycle is given in Fig. 1.2 and showing significant variation over time. The parameters were smoothed using a cubic spline filter to dampen the effect of outliers on the PCA analysis. Principal components (PCs) 1, 2 and 3 contained 96.08 % (respectively 57.97 %, 30.08 % and 8.03 %) of the total variance. From the correlation matrix (Table 1.1), it is clear that both +ΔP and S, and -ΔP and T are strongly correlated.

From the PC1 vs. PC2 biplot (Fig. 1.3), +ΔP and the slope (S) are almost uncorrelated with -ΔP, T and J. The +ΔP variance can be attributed to both reversible and irreversible fouling, whereas the -ΔP variance indicates fouling that cannot be removed by a (chemically enhanced) backwash. Combining the nature of the fouling from the biplot in Fig. 1.3 with the PC1 vs. PC2 scores in Fig. 1.4 (right) delivers an overview of the whole period and more insight in specific fouling events.

It can be derived from the score plot that the variation of -ΔP and J follow the long-term temperature dynamics (seasonal variation), whereas +ΔP and S increase on the short term in periods between chemically enhanced backwashes (CEBs). To assess the real contribution of J in relation to T, PC1 vs. PC3 and PC2 vs. PC3 were analysed, but the related score plots showed mostly scattered values and thus no clear trends (results not shown).

Remarkably, -ΔP, as indicator of irreversible fouling, was almost not influenced by CEBs. In the long run however, even if CEBs are only partly solving irreversible fouling, they are still necessary to improve the membrane state notwithstanding the greater effect of temperature. The short-term excursions of +ΔP and S, perpendicular to -ΔP, T and J, indicate both reversible and irreversible fouling that could be removed through CEBs. Short-term variation in PC2 between CEBs was highest when temperature was at a minimum (yellow dots, Fig 1.4), indicating that irreversible and reversible fouling rates are strongly depending on temperature. But while irreversible fouling decreased and thus the membrane state improved with increasing temperature, short-term excursions until the end of the 8-month period suggest that sludge filterability was still poor and resulted in high reversible fouling. It is noted that these preliminary results suggest that a rotation of the principal components to obtain meaningful factors could be useful (as in Maere et al., 2012). However, results are not conclusive at the time of writing.

In summary, PCA analysis was successfully applied to full-scale MBR data and found to be a useful technique to detect reversible and irreversible membrane fouling patterns in vast amounts of full-scale TMP data. Further improvement of the analysis is required as full-scale operation evidently has lead to more complex patterns in the collected data compared to the previously analysed lab-scale data. Nevertheless these results already show the potential of PCA for better understanding and monitoring of full-scale operation, confirming earlier findings at lab scale. This opens new perspectives for monitoring, diagnosis and control of membrane fouling merely based on TMP, temperature and flux data.

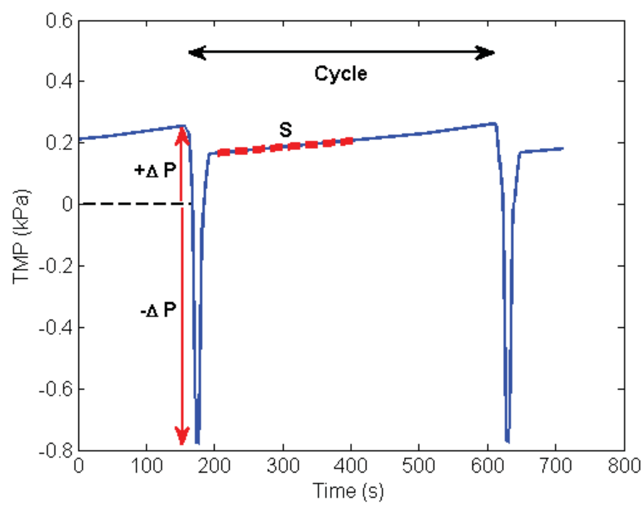

Figure 1.1: TMP cycle parameters for a typical filtration cycle beginning at t_1 when the pressure is reversed to backwash, depicting the filtration pressure peak (+ΔP), the backwash pressure peak (-ΔP) and the slope (S). Adapted from Maere et al. (2012).

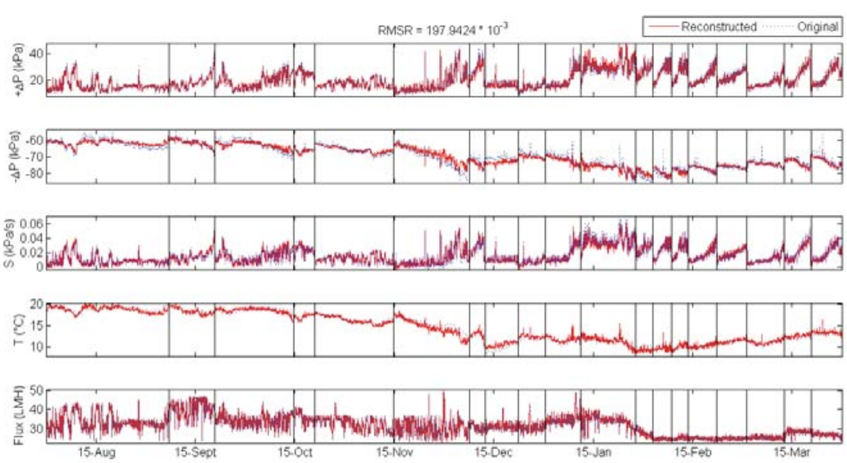

Figure 1.2: Smoothed values for the filtration pressure peak (+ΔP), the backwash pressure peak (-ΔP), the slope (S), Temperature (T) and flux (J) for each respective filtration cycle during 8 months (blue lines). Reconstructed parameter values based on 3 PCs (red lines). Black vertical lines indicate chemical enhanced backwash events.

Table 1.1: Correlation matrix on the 5 parameters used for PCA

R^2	+dP	-dP	S	T	J
+dP	1.0000	-0.6085	**0.9267**	-0.3568	0.0049
-dP	-0.6085	1.0000	-0.5110	**0.8251**	0.4999
S	**0.9267**	-0.5110	1.0000	-0.3235	0.0956
T	-0.3568	**0.8251**	-0.3235	1.0000	0.5118
J	0.0049	0.4999	0.0956	0.5118	1.0000

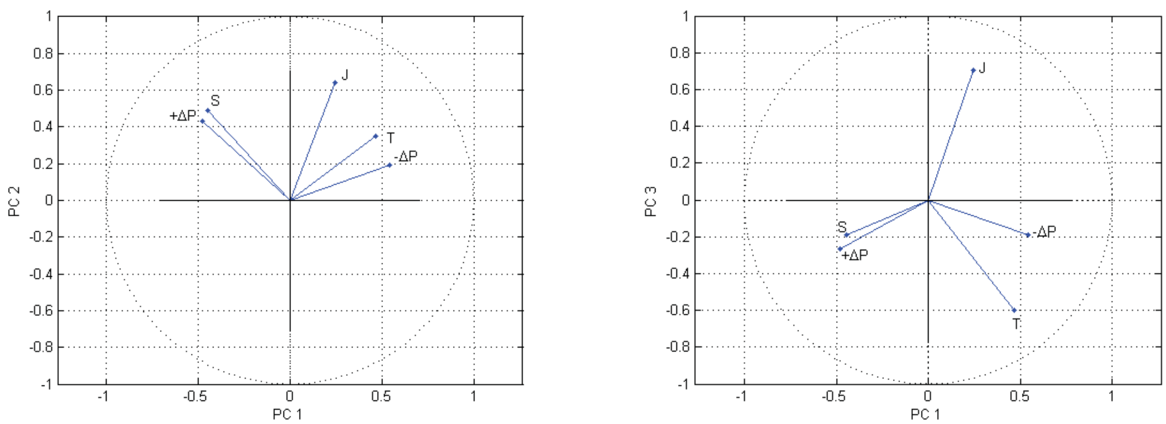

Figure 1.3: Biplots indicating the composition of PC1 vs. PC2 vs. PC3.

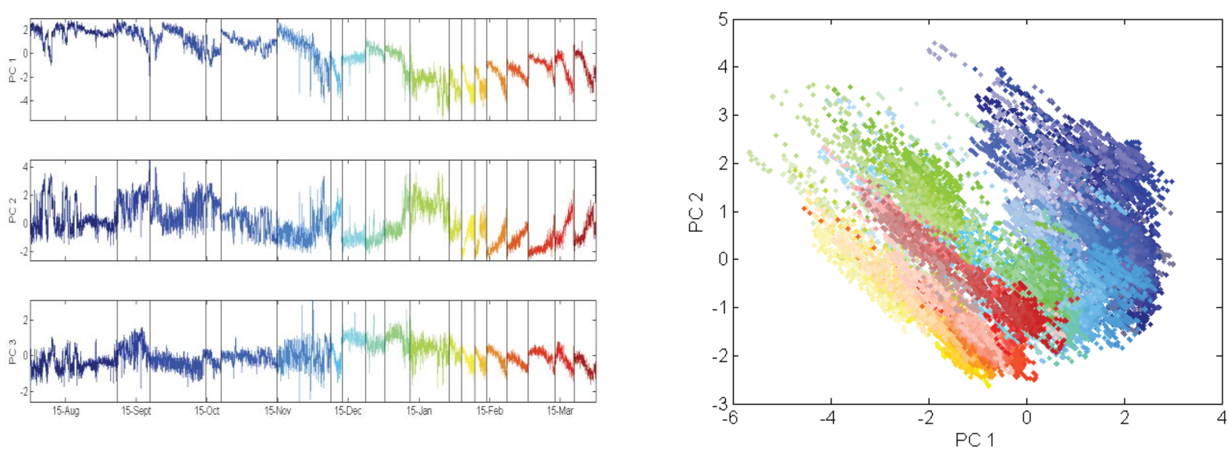

Figure 1.4: Time series of the first 3 PCs for all TMP cycles with chemical enhanced backwashes indicated (vertical lines) (left). PCA score plot for PC1 vs. PC2 (right). Every dot represents one filtration cycle (n=21753). Different colors were selected for the different periods separated by CEBs, going from blue (August 2011) to red (March 2012). Within each period, a color gradient is used from dark (after CEB) to more transparent (before next CEB).

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