Towards intelligent ultrafiltration for reverse osmosis seawater desalination pretreatment by means of PCA

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Abstract: A novel fouling monitoring methodology based on principal component analysis (PCA) has been validated using the operational data, mostly transmembrane pressure, of a pressurized ultrafiltration system operated with seawater. The evolution of membrane fouling was investigated in detail to determine its correlation with the cleaning strategy on one hand and the quality of the raw seawater on the other hand. The developed models showed that in terms of cleaning efficiency there are no significant differences between the standard protocol and the optimized operation. This confirms the hypothesis of being able to use the optimized operation in a sustainable manner and still benefit from lower cleaning frequencies. In addition, it has been demonstrated that the use of PCA as monitoring technique to detect abnormal fouling issues is a robust tool. By using PCA, decisions on cleaning sequences or frequencies could be taken dynamically instead of running the system with fixed cycles.

Keywords: Membrane fouling; monitoring; principal component analysis, ultrafiltration

Introduction

The use of pressurized ultrafiltration (UF) as pretreatment for reverse osmosis (RO) seawater desalination has increased significantly as a result of the continuous quest for cost-effective technologies that enable a sustainable production of water. Key benefits associated with the UF technology versus conventional pretreatment are its low footprint, the ability to remove viruses and bacteria and the significant reduction of colloids, suspended particles and turbidity. Even more important is its reliability in providing good quality filtrate for the downstream RO plant (Gilabert Oriol et al., 2013).

The UF process is characterized, unlike RO, by relatively short filtration cycles (10 to 90 minutes). The duration of the filtration cycles strongly depends on the quality of raw intake water. Between two filtration cycles a mechanical cleaning, typically a backwash (BW) is performed to clean the membrane fibres and reduce the transmembrane pressure (TMP). The TMP builds up while the unit is in filtration mode, especially when operating in dead-end mode. A second type of cleaning, taking place at a lower frequency, is the chemically enhanced backwash (CEB). Often, a CEB is done once per day or even once every few days and is characterized by a longer duration compared to a normal backwash and by the use of cleaning chemicals. Finally, a cleaning in place (CIP) occurs once every couple of months and typically lasts a few hours and uses a higher concentration of chemicals compared to a CEB (Gilabert Oriol et al., 2013). Since membrane cleaning leads to process downtime, chemical consumption and potentially a reduction in membrane lifetime because of exposure to chemicals, it is important to apply the cleanings available, i.e. BW, CEB and CIP, optimally and only when really required. Therefore, in this study an attempt is made to monitor the UF process intelligently in order to apply the cleaning measures optimally and save costs.

Material and Methods

Principal component analysis (PCA), a relatively straightforward data mining technique often used to unravel data patterns in large datasets and previously successfully applied to a lab-scale membrane bioreactor (MBR) (Maere et al., 2012), was used to analyse the high-frequency TMP data from an experimental containerized desalination plant. The vast amount of measurements were reduced into three parameters for each membrane filtration cycle, i.e. filtration pressure peak (+ΔP), backwash pressure peak (-ΔP) and the TMP slope during filtration (S) (Figure 1a), before PCA was applied (Figure 1b).

Figure 2 depicts the pilot-scale installation consisting of two independent and parallel lines, both containing DOW™ Ultrafiltration SFP-2660 PVDF membrane modules as pretreatment to the reverse osmosis train. The normal backwash operation consists of five consecutive steps summarised in Table 1. However, to reduce the downtime during backwashing a more optimal backwash scheme was proposed (see Table 1), supposedly with the same cleaning efficiency.

Results and Conclusions

Four different datasets were analysed, i.e. period 1 from 8 - 16 August and period 2 from 14 - 28 September 2012, and each period is split up in two parallel UF lines, i.e. UF1 and UF2. Normal backwash settings were used throughout except for period 2 - UF1 where the optimized settings were applied as mentioned before. As such the subfigures ‘a’ and ‘b’ in Figures 3 and 4 give an indication on the repeatability of the analysis within each period, while ‘b’ and ‘d’ give an indication on the differences between periods, for instance because of different sea water qualities, and ‘c’ and ‘d’ give an indication on the impact of the different backwashing strategies.

All datasets needed 3 principal components (PCs) to explain more than 95% of the variance in the data. The amount of variance explained by PC 1 varied between 50 and 60%, while PC 3 only accounted for 10 to 15% and eventually was left out of the analysis as it potentially focuses on noise. Figure 3 shows how PC1 and PC2 are composed out of the original variables +ΔP, -ΔP, and S. The angles between the variables in the biplots give an indication on their correlation (90° angle for uncorrelated variables). The PC scores in Figure 4 map the different filtration cycles in the space of PC1 and PC2. Each point depicts a filtration cycle. The colour scale indicates time: blue and red for filtration cycles respectively in the beginning and end of the studied periods.

The PC models of two parallel UF lines within the same period appear similar, while big differences are visible for the different periods. This could be explained by a different quality of sea water (suspended solids, turbidity) in the two periods. The models for UF operation with and without optimized backwash conditions are almost alike (Figure 3c - 3d) as well as the scores (Figure 4c - 4d), meaning that the cleaning efficiency remains good and might even be further optimized. The outliers at the top of Figures 4c - 4d illustrate the possible use of PCA as monitoring technique to detect abnormal fouling issues. In this way decisions on backwashing could be taken directly and dynamically based on measurements instead of running the system with fixed cycles. More details on the analysis and interpretation will be provided in the full paper.

References

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Maere, T., Villez, K., Marsili-Libelli, S., Naessens, W., Nopens, I., 2012. Membrane bioreactor fouling behaviour assessment through principal component analysis and fuzzy clustering. Water Research 46 (18), 6132-6142.

Figures and Tables

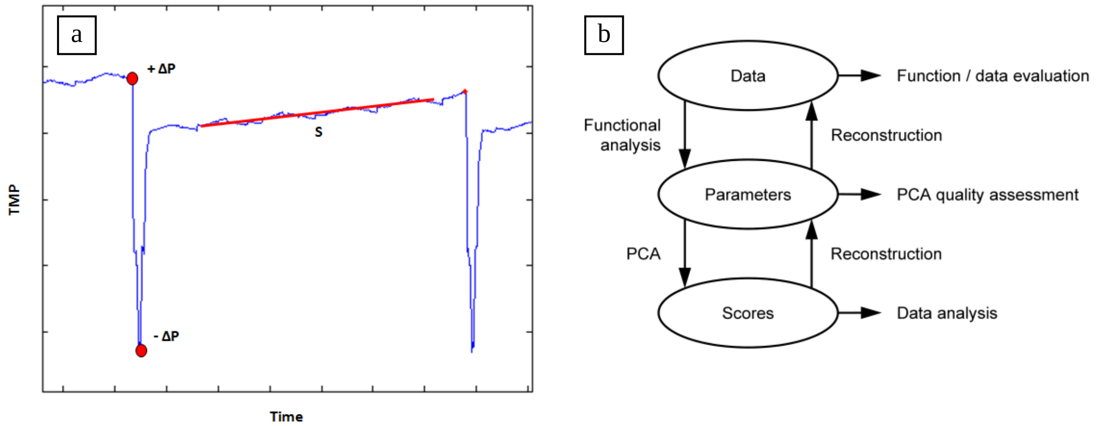

Figure 1 Parameter estimation for a single filtration cycle (a) and general approach to PCA (b - after Maere et al., 2012)

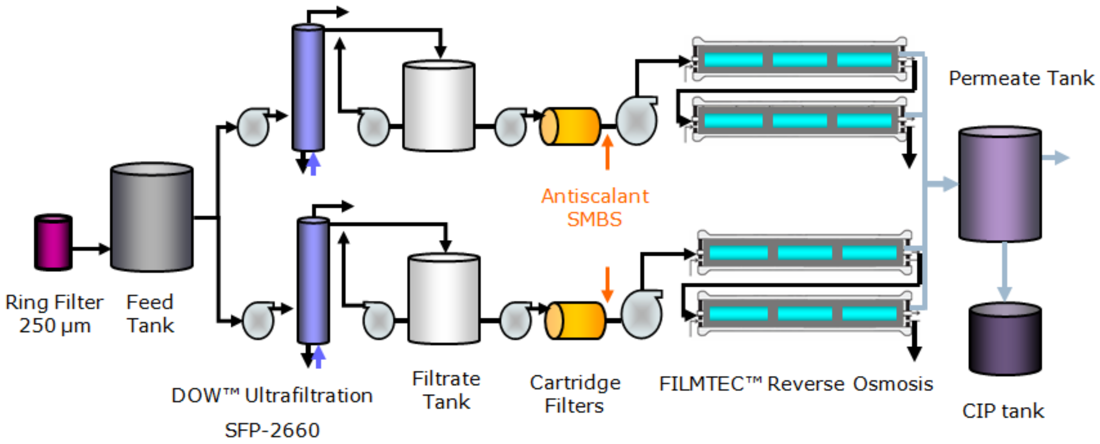

Figure 2 Pilot-scale seawater reverse osmosis desalination plant with ultrafiltration pretreatment.

Table 1 Baseline and optimized filtration and backwash conditions for the ultrafiltration membranes.

Parameter	**Baseline**	**Optimum**
Flux	70 l/m^{2}h	70 l/m^{2}h
Backwash frequency	90 min	90 min
Backwash flux	80 l/m^{2}h	80 l/m^{2}h
Air flow	12 Nm^3/h	12 Nm^3/h
Air Scour duration	30 s	-
Draining duration	30 s	-
Backwash Top with Air Scour duration	30 s	60 s
Backwash Bottom duration	30 s	-
Forward Flush duration	30 s	30s
Valve changing time	2 s	2 s
CEB frequency	24 h	24 h
NaClO Concentration	350 mg/l	350 mg/l
Soaking time	6 min	6 min

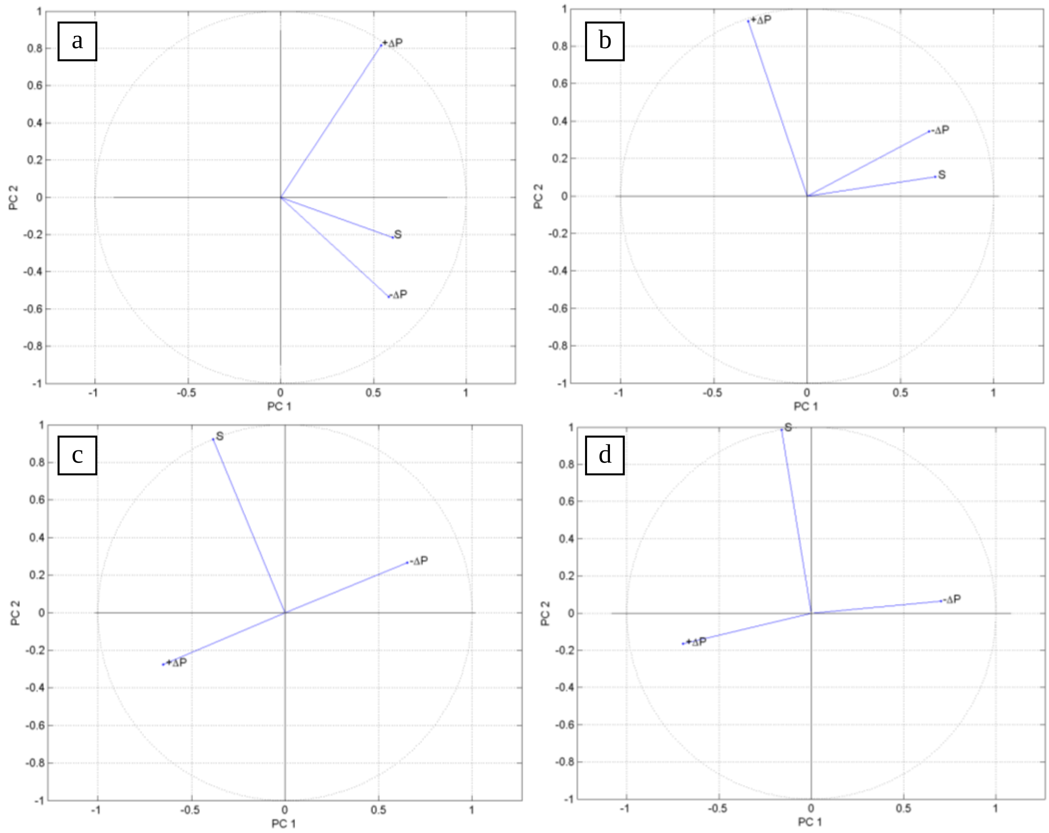

Figure 3 PCA loadings for PC1 and PC2 for period 1 - UF line 1 (a), period 1 - UF line 2 (b), period 2 - UF line 1 (c), period 2 - UF line 2 (d).

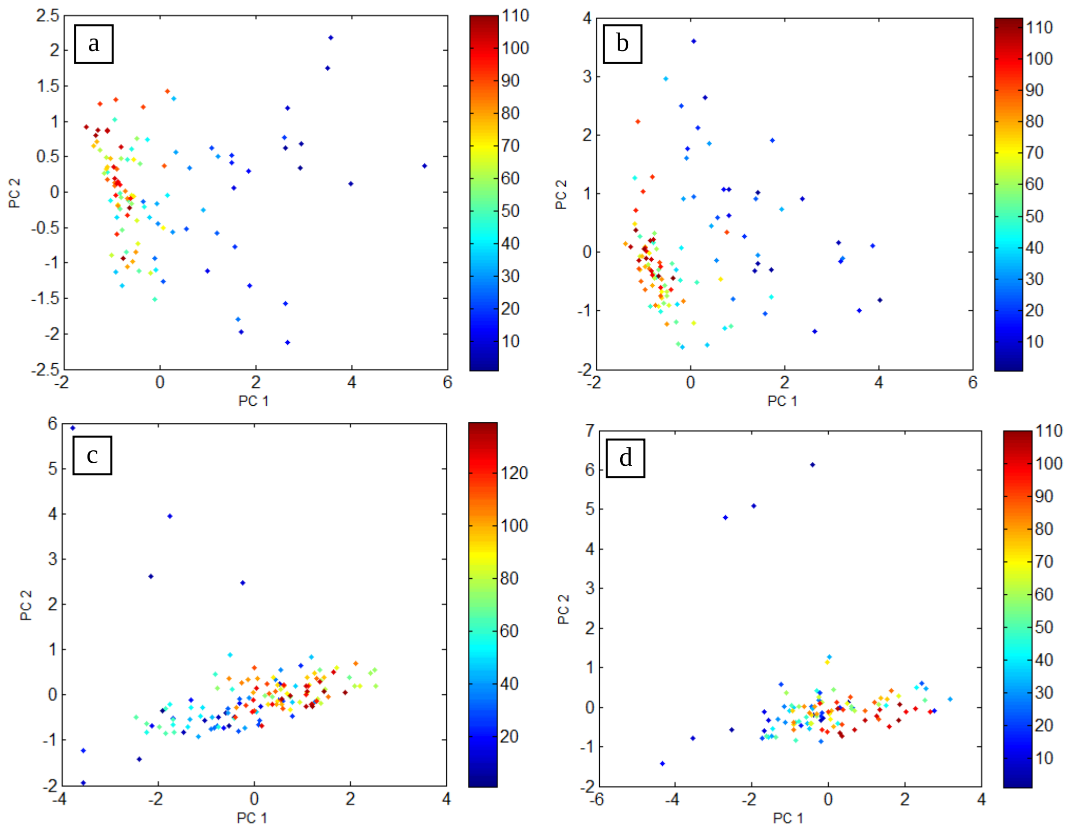

Figure 4 PC1 and PC2 scores for P1 - UF1 (a), P1 - UF2 (b), P2 - UF 1 (c), P2 - UF2 (d).