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Modelling the long-term evolution of permeability in a full-scale MBR: Statistical approaches

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HIGHLIGHTS

- We monitored a full-scale membrane bioreactor for one year.
- Six operating variables and three fouling indicators are used.
- SRT, temperature, flux and organic loading are correlated with long-term fouling.
- MLSS and iron additions have a limited impact on long-term fouling.
- Statistical prediction of long-term permeability evolution is attempted.

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ABSTRACT

Even if fouling in membrane bioreactors (MBRs) has been extensively studied during the last decade, its causes and mechanisms are not well understood yet. Furthermore, few full-scale and long-term experiments have been published, and their results do not always match with the models developed from lab-scale studies.

A statistical approach linking long-term and short-term permeability evolution with operational variables in full-scale membrane bioreactors for domestic waste-water treatment is presented. Data originate from a 66,700 P.E. MBR plant monitored for more than one year. Permeability and several fouling indicators were calculated in each of the four hollow-fibre membrane tanks of the plant. The influence of SRT, temperature, MLSS, F:M ratio, iron dosing and membrane flux on daily permeability evolutions, instantaneous permeability evolution and hydraulic backwash efficiency was studied. In order to minimise the bias due to correlations between input variables, a statistical approach using principal component regression and partial least-square regression was tested. Flux, temperature, SRT and F:M ratio are the most influential input variables on long-term permeability evolutions. Iron dose and MLSS are less correlated with fouling indicators. The proposed approach may be improved by integrating the history of the membrane to better describe and predict the permeability evolution.

1. Introduction

Over the last decade, filtration in membrane bioreactors (MBRs) has been extensively studied since fouling and the related energy consumption to mitigate it are one of the main bottlenecks for the development of this technology [1]. To help filtration design and operation, different models have been proposed and calibrated, essentially based on lab-scale and pilot-scale experiments.

On the one hand, mechanistic models based on physical filtration laws have been proposed. Resistances in series coupled with mass balances are the most common approach [1–5]. Applications of these models have been restricted to relatively short-term periods, mostly in the range of 1 h–10 d and exceptionally up to 65 d. These models contain a large number of parameters and variables, such as sludge supernatant composition and especially soluble microbial products (SMPs) concentration, shear stress, or size distribution of particles and membrane pores. A few other mechanisms have been highlighted in exploratory studies, but they are poorly quantified and formalised in models. Examples include the protection of membranes against deep

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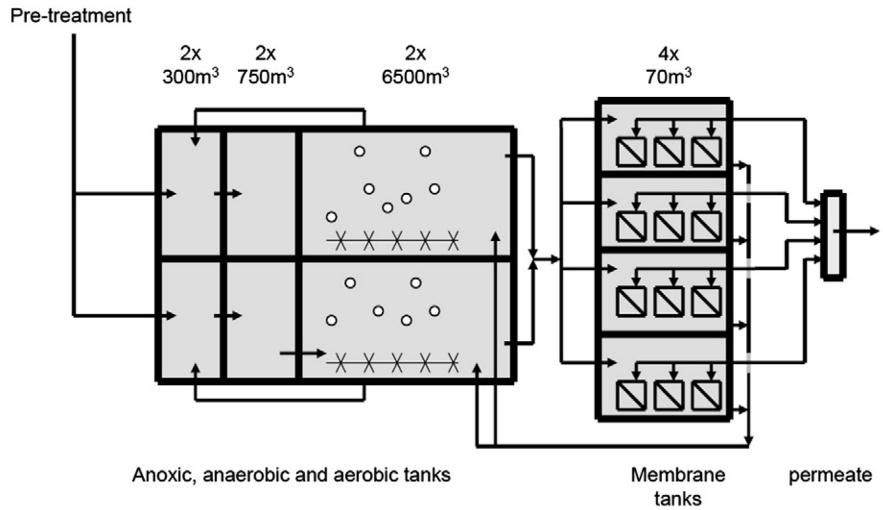

Fig. 1. Simplified MBR layout.

fouling by the cake layer [6], or the role of the nature of SMP (protein/polysaccharides/humic substances) in their ability to attach to the membrane. Many studies highlight polysaccharide predominance in fouling [7–9] but for others, the protein content in the colloidal phase [10,11] or humic substances [12] is the main factor. Since experimental conditions and analysis methodologies differ, comparing these studies can be very complex. Furthermore, they allow to identify mechanisms but not to quantify their contributions to overall fouling.

On the other hand, empirical models based on statistical analysis of data can integrate unknown mechanisms in multivariate linear correlations [13–15].

On full-scale plants, only two of the reviewed studies aim at modelling permeability [16,17]. The model of Wintgens et al. [16] was upgraded and implemented in the GPS-X software by Sarioglu et al. [5] on a long pilot plant monitoring period. The model is based on resistances in series with cake deposition and a mass balance of SMP inside the membrane to make internal fouling increase with the cumulated filtered volume. Cake deposition has an impact only when filtration experiences a process upset. Ludwig et al. [17] use almost the same concepts and obtain good results for transmembrane pressure (TMP) simulation, but only for short periods (1–4 day validation periods). Unlike in most full-scale data found in literature [18], no progressive increase of permeability is modelled in these studies. This is probably because mechanical and chemical cleaning (backwashing, maintenance cleaning) is not, or poorly, accounted for in the models. Also, some of the more complex mechanisms described previously are not considered in models calibrated on large-scale experimental setups. In full-scale MBRs, the limited monitoring of operating conditions doesn't allow this kind of detailed study. A prior statistical analysis between sludge characteristics, operating conditions and fouling may provide a deeper insight into the predominant fouling mechanisms and their respective weights.

The aim of this study is to present a statistical analysis of operational conditions (flux, $FeCl_3$ dose), sludge characteristics (SRT, F:M ratio, temperature, and MLSS) and fouling indicators. A full-scale MBR with four parallel membrane tanks (MTs) equipped with hollow-fibre membranes was monitored for one year. Appropriate sequences of flux used in pilot-scale membrane bioreactors to characterise fouling are not feasible in full-scale. However the availability of a wide range of flux variations (15 to 50 LMH) in the full-scale plant, even erratic, can be used with appropriate data processing. Three fouling indicators were calculated to get the most information out of full scale data that are not initially designed for fouling characterization in a research context.

First, a principal component analysis (PCA) was conducted on input variables to identify their correlations, and a principal component regression (PCR) was conducted to analyse links between main groups of variables and fouling indicators. Then a partial least square regression (PLSR) was used to highlight which variables or groups of variables are best correlated with these indicators. The prediction ability of these approaches is then discussed and the perspective of improving the models is commented.

2. Materials and methods

2.1. MBR plant description

A MBR plant in the Paris area designed for 66,700 P.E. (Fig. 1) was monitored for one year. The mixed liquor from the two biological

Table 1
Main characteristics and operational variables of the MBR during period 1.

Plant-wide data	Design capacity	66,700 P.E. 10,500 $m^3 \cdot d^{-1}$ 11,100 kg $COD \cdot d^{-1}$
	Average influent flow rate	8200 $m^3 \cdot d^{-1}$
	Activated sludge tanks volume (anoxic + anaerobic + aerated tanks)	2 × 7550 m^3
	Membrane tanks volume	4 × 70 m^3
	Pre-treatment	Grit removal, fat removal, sieving 0.8 mm
	SRT	50–70 d
	HRT (for average flow rate)	38 h
Membranes	Membrane type	Hollow fibre ZeeWeed 500d (GE-Zenon)
	Mean pore size	0.04 μm
	Material	PVDF
	Membrane area	4 × 4550 m^2
	Filtration flux	10–50 LMH
	Instantaneous SAD_m	0.62 $Nm^3 \cdot m^{-2} \cdot h^{-1}$ (50% of the time)
Activated sludge	Average organic loading	4200 kg $COD \cdot d^{-1}$
	Average F:M ratio	0.052 kg $COD^{-1} \cdot kg\ MLVSS^{-1} \cdot d^{-1}$
	MLSS (aeration tanks)	5–9 $g \cdot L^{-1}$
	MLSS (membrane tanks)	6–10 $g \cdot L^{-1}$
	MLVSS	4.5–6 $g \cdot L^{-1}$
	Temperature	10–21 °C
	Average iron dose	Winter: 90 kg $Fe \cdot d^{-1}$ (8.8 mg $Fe/L_{influent}$) Summer: 140 kg $Fe \cdot d^{-1}$ (18 mg $Fe/L_{influent}$)