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Model-based selection of the best viable operational strategy for a full scale MBR

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Summary of key findings

The operation of a full-scale Membrane Bioreactor (MBR) facility treating municipal wastewater was evaluated using a model-based approach. Different viable alternatives to improve process performance and to save energy were simulated and compared based on effluent quality, operational costs and risk of foaming and bulking due to the filamentous bacteria growth. The reduction of the aerobic tank dissolved oxygen (DO) set-point was selected and successfully implemented in the full-scale MBR, showing a reduction up to 27% of NO_3^--N concentration in the permeate and 7% saving in the biological aeration cost.

Background and relevance

MBRs have become an excellent alternative to the conventional activated sludge process for municipal wastewater treatment, especially when water reuse is needed (Judd, 2011). However, operational costs still remain as one of the main obstacles of this technology, mainly associated with aeration (Judd, 2011; Brepols et al., 2010).

Modeling and simulation tools are invaluable, in terms of time and effort needed to test different "what if" optimization strategies for improving effluent quality and reducing energy costs (Rivas et al., 2008), as well as for providing insight on underlying mechanisms affecting process performance. Since most MBR facilities are operated conservatively based upon manufacturers' recommendations, there has been limited research on full-scale MBR process optimization.

The aim of this study is to identify and implement the best viable operational strategy of a full-scale MBR through a model-based approach.

The full-scale WWTP is designed to treat 15,000 $m^3 \cdot day^{-1}$ through MBR technology. The bioreactor has two anoxic zones and two aerobic zones for denitrification and nitrification processes, respectively, followed by three parallel membrane compartments (hollow fiber, GE Zenon) with a total membrane surface of 22,752 m^2. The sludge is recirculated from the end of the aerobic zone to the beginning of the anoxic zone through an internal recirculation and from the membrane tanks to the aerobic zone through the external recirculation. $FeCl_3$ is added previous to the anoxic tank to remove phosphorous. The biological model used to describe the plant was ASM2d (Henze et al., 2000), while a resistance-in-series model was used to describe membrane behavior (Dalmau et al., 2013). The simulation platform used was WEST® (mikebydhi.com). Averaged data from the historical data set was used to calibrate the plant in steady state. Data from a 3-day exhaustive experimental campaign was employed to calibrate and validate the dynamic state model. Mean Square Relative Error method (MSRE) evaluated the goodness of fit between the simulation results and measured data during the calibration and validation phase. The criteria selected to compare the operational alternatives were the Effluent Quality (EQ) and the Operational Cost (OC, expressed as aeration energy and pumping energy) developed for the Benchmark Simulation Model (Jeppsson, et al., 2007; Nopens et al., 2010), and the microbiology-related solids separation problems qualitative risk index (Comas et al., 2008).

Results

The operation of the full-scale MBR was characterized (nutrient removal efficiencies, sludge properties and filtration performance). Despite the fact that the MBR was working properly, there was room for improvement for N removal efficiency, specifically for the denitrification step (with high concentration of nitrates at the permeate stream). Moreover, nitrification was nearly completed before the membranes tank. Three operational parameters were simulated to reduce the energy costs and improve the nitrogen removal efficiency: (i) Aerobic tank DO set-point, (ii) external recycle flow rate and (ii) internal recycle flow rate. Since more than 50% of the estimated costs distribution of this facility was due to the blowers, the focus was first placed on optimizing the biological aeration.
The effect of three different DO set-points (DO: 1.0, 0.8 and 0.5 mg·L^{-1}) was simulated and compared to a baseline reference scenario representing the real operational conditions (DO: 1.2 mg·L^{-1}). Results showed a positive impact on the effluent quality by decreasing the DO set-point. Specifically, the NO$_3^-$-N concentration decreased by almost 2 mg·L^{-1} when the DO set-point was reduced in the model from 1.2 to 0.5 mg·L^{-1}. The model confirmed what was expected mechanistically because less DO is recycled to the anoxic zones, allowing for better maintenance of anoxic conditions, and hence better heterotrophic denitrification. Likewise, the predicted biological aeration energy consumption decreased by approximately 14 % with the DO reduction (Figure 1.1). On the other hand, the presence of severe risk of filamentous bacteria growth due to the low DO increased from 0 to 3 % when the DO set-point was decreased from 1.2 to 0.5 mg·L^{-1}, while it did not increase when DO set-point was set at 0.8 mg·L^{-1}. These results showed that working at 0.5 mg·L^{-1} could deteriorate the sludge properties, despite the highest energy savings. In order to avoid possible foaming problems, the DO set-point scenario considered to be applied in the full-scale MBR was 0.8 mg·L^{-1}.

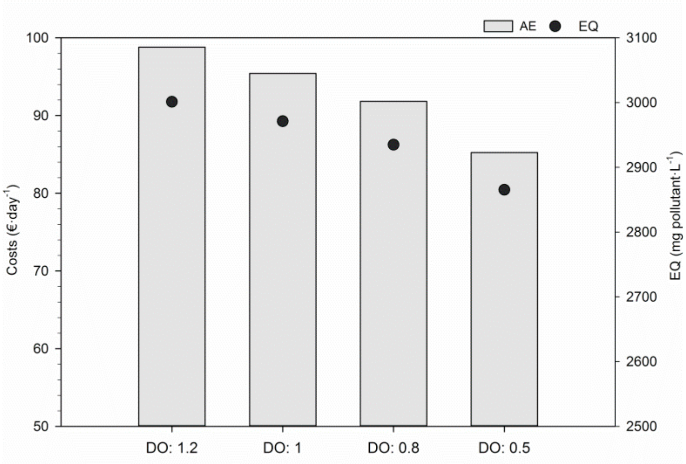

Figure 1.1 Costs and effluent quality for the four different DO scenarios.

Besides, after fixing the second aerobic tank DO set-point to 0.8 mg·L^{-1}, four different flow rates were tested through simulation for external and internal recirculation flows, taking into account the pump capacities. Figure 1.2 shows the effluent quality and costs for each alternative. The lowest EQ correlates with the highest recirculation rate values, and consequently, with the highest pumping costs. From these results, it is possible to determine that there is a trade-off between operational cost and effluent quality (reducing vs. increasing internal/external recirculation flow rate). For this reason, recirculation flow rate modification was not included in the optimization strategy applied to this particular case study. However, it should be considered in other full-scale applications, especially in cases where the denitrification is not as sensitive and has less impact on EQ value.

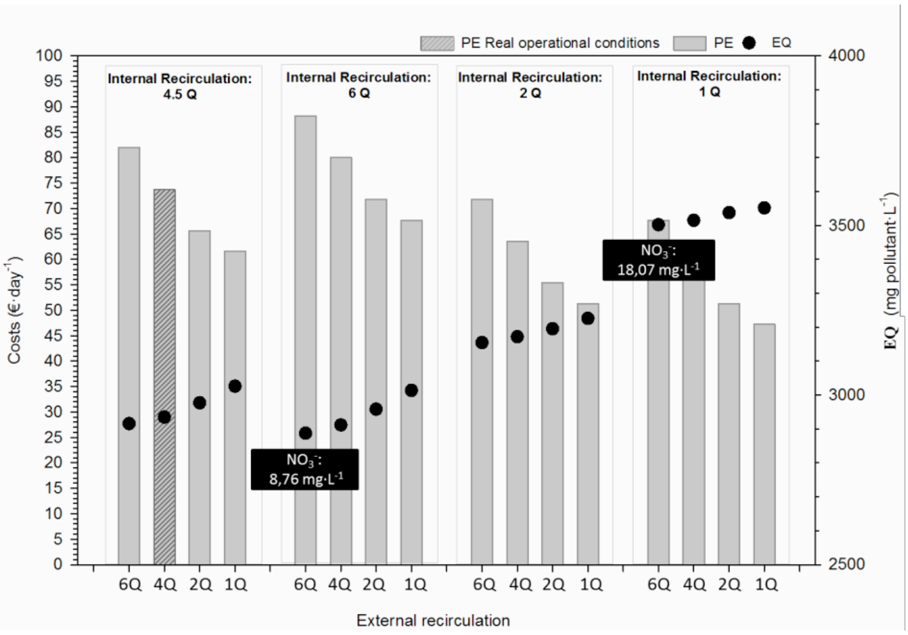

Figure 1.2 Costs and EQ values for the different external and internal recirculation ratios.

Afterwards, the most viable operational strategy identified through the model-based scenario analysis (i.e. reducing the second aerobic tank DO set-point from 1.2 to 0.8 mg·L^{-1}) was implemented in the full-scale MBR. This implementation confirmed a reduction in practice of up to 27 % of NO_3^--N concentration in the permeate, when the influent C:N ratio was adequate. Likewise, the DO set-point reduction decreased the airflow provided to the second aerobic tank, and consequently, a 7% saving on the biological aeration costs was achieved based upon the OC criteria. Moreover, other optimization alternatives (i.e. carbon source addition) were evaluated using the model but they were rejected since they were considered not viable in the full-scale MBR.

Discussion

This study has presented the operational optimization of a full-scale MBR. Despite of operating reasonably well, this facility showed room for improvement for N removal efficiency and for energy saving. Through a simplified modeling exercise it has been possible to compare different operational strategies to identify the most viable one. This has been implemented in the full-scale MBR showing successful improvements and demonstrating that this methodology is accurate enough for full-scale applications.

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