Performance evaluation of the benchmark simulation model for membrane bioreactors extended with membrane filtration and fouling

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Introduction

During the last decades, membrane bioreactors (MBR) evolved from a promising towards an effective technology for wastewater treatment. The fouling process of the membrane surface remains the main issue, inducing a high energy demand and hence operational cost. The causes of the fouling mechanisms are different, complex and to date not fully understood and requires a vast amount of lab experiments. Therefore, a modelling approach represents a valid alternative to understanding MBR behaviour. The possibility to analyse numerous virtual simulations of different model configurations in a short time frame represents a powerful instrument to optimize this kind of systems (Naessens et al. 2012). The scope of this work is to take membrane modelling a step further, extending an acknowledged filtration model (Jiang, 2007), introducing a constant volume hypothesis and incorporating it in the Benchmark Simulation Model platform for MBRs (BSM-MBR, Maere et al., 2011).

Extended BSM-MBR model

The MBR and membrane filtration models were developed in the WEST® modelling and simulation platform (mikebydhi.com). Compared to the previous BSM-MBR configuration where backwash, relaxation and fouling are not physically modelled (Maere et al., 2011), more realistic membrane cycles are considered, each being composed of a filtration period of 600 s (10 min), a backwash period of 30 s, and a relaxation period of 60 s, for an overall duration of 11.5 minutes with a backwash flux of 20 LMH. These values are typical for HF membranes, as reported in the literature (Judd & Judd, 2011).

Mass balance In BSM-MBR, tank volumes were considered constant. However, with the incorporation of more realistic filtration cycles this is not possible anymore and the volume of the membrane tank now changes dynamically. Moreover, an additional tank had to be added to provide the backwash flow and regulate the overall mass balance around the membrane. To add realism to the model and minimize the disturbance introduced by this additional component, the backwash tank was designed for the least possible volume, in order to avoid any unnatural smoothing of the effluent peaks and yet prevent the risk of running empty. As a result the tank volume was selected as twice that needed for backwashing.

Fouling The fouling model is derived from the previous work by Jiang (2007) and it is based on the resistances-in-series approach. The transmembrane pressure (TMP) at time t ΔP(t), is expressed in kPa by the following eq. (1)

$$\Delta P(t) = \eta_p J_G(t) \cdot \left[R_m + R_{irr}(t) + R_c(t) \right], \quad (1)$$

where η_p is the viscosity of the permeate (Pa.s), J_G is the global flux (m d^{-1}), R_m the clean membrane resistance (m^{-1}), R_{irr} the hydraulically irreversible resistance (m^{-1}), and R_c the cake resistance (m^{-1}).

The aeration processes (biomass aeration and membrane aeration for fouling reduction) are based on the model developed by Maere et al. (2011).

Filtration flux control The simplifying assumption of the extended BSM-MBR model is to consider a constant filtering surface. A multiband filtration flux virtual control was added so that the membrane tank volume would not deviate too much from the design value. The flux range is determined by the tank volume, with the maximum value corresponding to the net flux required for peak flow. However from the simulations it emerged that this controller caused severe oscillations in the membrane tank volume and in the effluent flow. To decrease this disturbance this hard-threshold controller was substituted with a smoother fuzzy controller, defined by the membership functions of Figure 1 and the rules of Table 1.

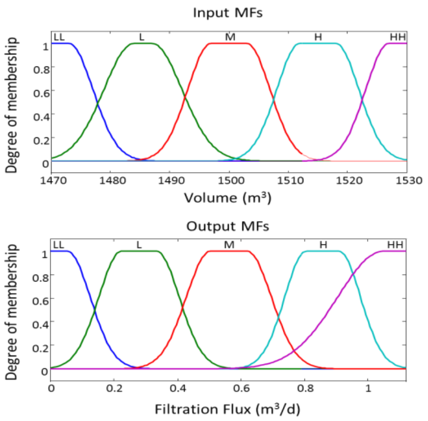

Figure 1. Input-output membership functions of the fuzzy controller.

Table 1. Fuzzy rules for the filtration flux

1. If (Volume is LL) then (Filtration_Flux is LL)
2. If (Volume is L) then (Filtration_Flux is L)
3. If (Volume is M) then (Filtration_Flux is M)
4. If (Volume is H) then (Filtration_Flux is H)
5. If (Volume is HH) then (Filtration_Flux is HH)

An example of rules activation is shown in Figure 2. After generating the input-output control curve, shown in Figure 3, obtained by combining all the features of the fuzzy controller, this was approximated by a 4th order polynomial and ported into WEST as a custom algebraic controller[1].

Testing procedure The new plant configuration, including the internal volume to filtration flux controller, was simulated in steady-state conditions assuming an initial membrane tank volume of 1500 m^3 and a buffer tank volume of 20 m^3. The range of the filtration flux was set between 0 and 46.5 (LMH).

The simulation procedure was based on the BSM1 protocol (Copp, 2002) for which the simulated horizon of the different weather conditions (dry, rain, storm) is typically 3 weeks of dynamic dry weather and 1 week of dynamic dry, rain or storm. The last

[1] In the final paper an improvement will be proposed, implementing the fuzzy control curve as a look-up table.

week is the evaluation period. It should be noted, however, that this simulation length is appropriate for evaluating the effect of reversible fouling (short-term mechanism), whereas it is too short for studying the irreversible fouling mechanism, typically developing over longer periods (6 – 12 months) (Drews, 2010).

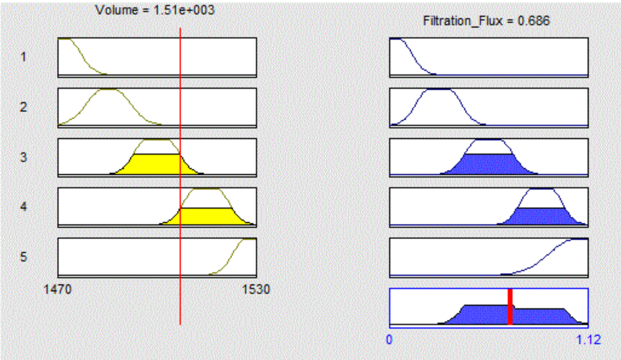

Figure 2. An activation example of rules of Table 1: the thick bar at the right indicates the actual output.

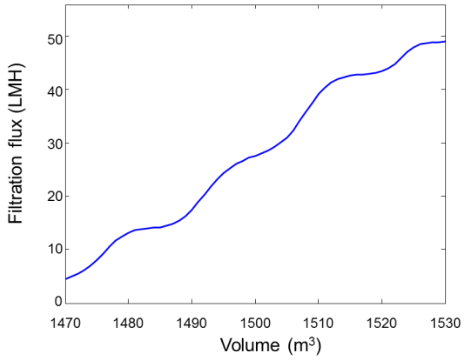

Figure 3. The input-output control curve produced by the fuzzy controller.

Discussion

The dynamic simulations are generally comparable to the old BSM-MBR results, though there are some differences regarding the biological variables. These are described in Barni (2012) and will be outlined in the full paper. However, these differences are unimportant in the membrane model context and do not indicate a modified biokinetic behaviour of the plant. It was observed that during the end of the simulation horizon, between day 24 and 28, an increasing fraction of membrane area was blocked by fouling (i.e. pore blocking), showing an irreversible resistance trend, as shown in Figure 4. This increase depends mainly on the flux, which oscillates widely when controlled by the multiband mechanisms to match the higher influent flows. These oscillations of the filtration flux which are detrimental for the short-term model behaviour, are produced in an attempt to stabilize the membrane tank volume and they are transferred to the buffer tank volume, and consequently on the effluent flow, adding to the cyclical backwash as a disturbance. The fuzzy alternative to this flux control is capable of reducing the oscillations regarding the influent and effluent flows (Figure 5) and the membrane volume (Figure 6).

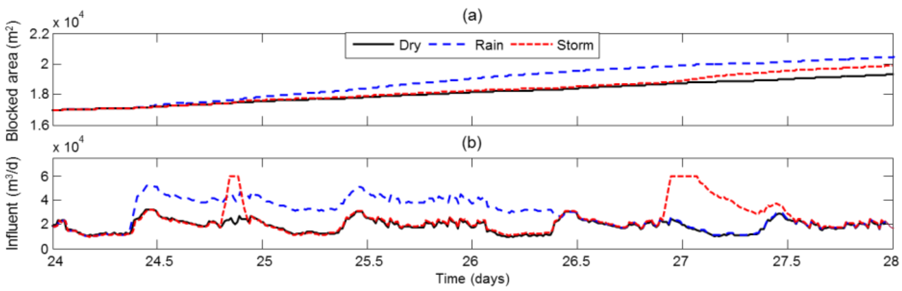

Figure 4. Increase of the membrane blocked area (a) depending on the influent (b) as a result of irreversible fouling for dry, rain and storm events.

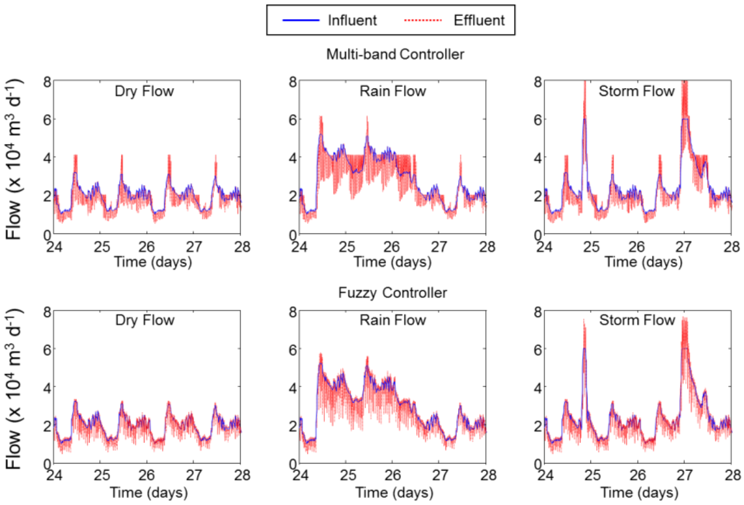

Figure 5. Comparison between the multiband and the fuzzy controller in the input-output flows in the membrane model.

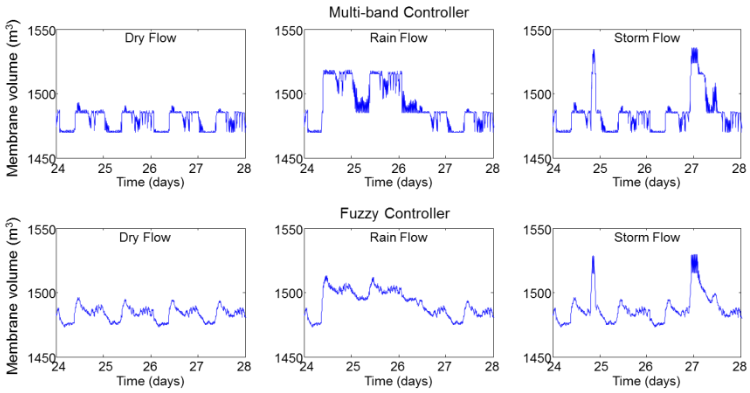

Figure 6. Comparison between the multiband and the fuzzy controller in the volume dynamics of the membrane tank.

In this paper an attempt is made to integrate a filtration model in the BSM-MBR configuration and summarises the work more thoroughly described in Barni (2012). The simulations presented here may be used to consider the following new research issues and needs: (1) New scenarios with a range of different parameter values for the fouling model could be investigated. (2) The dynamic behaviour of the controlled tank volume could be improved by developing a closed loop controller capable of tracking a variable volume set-point. Furthermore, the controller could be extended to dynamically adapt the membrane area in operation next to membrane flux.

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