CHEMICAL ENGINEERING TRANSACTIONS Volume 25, 2011
Editors Jiří Jaromír Klemeš, Petar Sabev Varbanov, Hon Loong Lam
Copyright © 2011, AIDIC Servizi S.r.l., ISBN 978-88-95608-16-7 ISSN 1974-9791
DOI: 10.3303/CET1125045

Submerged Membrane Bioreactors for Wastewater Treatment. Multi-Objective Optimization

Pompilia Buzatu*, Vasile Lavric

University Politehnica of Bucharest, Chemical Engineering Department
RO-011061, Polizu 1-7, Bucharest, Romania, p_buzatu@chim.upb.ro

In this paper we first optimized the operating parameters of a submerged membrane bioreactor for wastewater treatment using a dual-objective function: the global conversion of ammonia plus ammonium nitrogen and the weighted productivity of the system. Given the dichotomy of these two objectives, a Pareto front was obtained and the results analyzed. Consequently, a new operating strategy was proposed and optimized, namely the discontinuous mode until the microorganisms reach a convenient concentration in the bioreactor, followed by the original semi-continuous operating mode. In order to optimize this new operating strategy, the first objective function becomes the minimum between the global conversions of ammonia plus ammonium nitrogen and the soluble biodegradable substrate.
The point of the front having the productivity and conversion closest to those of a previously tested operating strategy was chosen to solve the mathematical model describing the system in order to compare the strategies.

1. Introduction

Submerged membrane bioreactors (SMBRs) are the in-situ combination of a suspended growth bioreactor with a membrane process, where the membrane primarily replaces the clarifier, which ensures high biomass concentrations in the conventional systems. Used in wastewater treatment, SMBRs lead to a number of advantages as compared with the aforementioned conventional technologies (Arevalo et al., 2009; Dialynas and Diamadopoulos, 2009; Meng et al., 2009; Teck et al., 2009).
Only a few attempts were made for optimizing SMBRs operating in wastewater treatment. Schoeberl et al. (2005) studied the influence of suction and backwash times, and aeration intensity on fouling, using a complete factorial experiment. Zarragoitia et al. (2009) tried to separately optimize the transmembrane pressure, the permeate volume and the energy consumption of a SMBR.
In this context, our study aims at contributing to the SMBR optimization field using mathematical modelling and simulation in white experiments, while searching for the appropriate objective functions to improve the operating strategy of this system.

Please cite this article as: Buzatu P. and Lavric V., 2011, Submerged membrane bioreactors for wastewater treatment. multi-objective optimization, Chemical Engineering Transactions, 25, 267-272
DOI: 10.3303/CET1125045

2. The physical and mathematical models

The system to be optimized (Di Bella et al., 2008) is schematically presented in Figure 1. The wastewater stored in tank (1) enters the MBR (2) where the pollutants are transformed by the activated sludge. The permeate, free of solids, is sucked through the membrane module for a given time (the filtration period), till the cake thickness becomes too high, and stored in tank (3). Then, the backwashing/cleaning period starts: the feeding and permeate suction are interrupted and a flow of permeate equal to the wastage line flow – sludge removed to stop accumulating the dead cells – is pumped back through the membrane in order to clean it up. The wasted sludge is withdrawn from the bottom of the reactor, with a constant, continuous flow throughout the whole working period and stored in the tank (4). The air is provided through three spargers – two of them located at the bottom of the reactor and one at the bottom of the membrane module – and is used to ensure the appropriate oxygenation of the liquid phase, according to the microorganisms' consumption, the efficient mixing of the liquid and the membrane scouring. The process stops when the whole volume of water passes from tank (1) through the bioreactor.

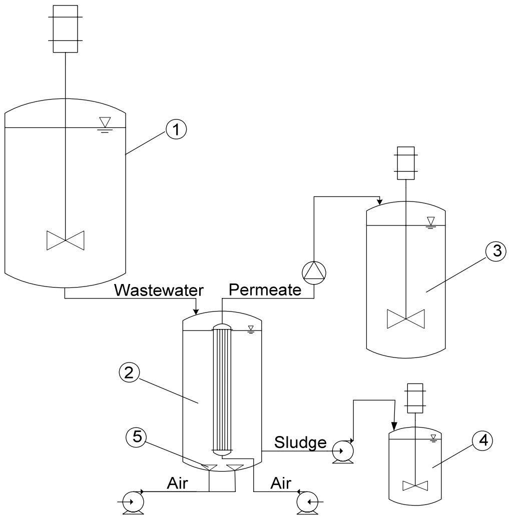

Figure 1: The experimental set-up:1.wastewater tank; 2.membrane bioreactor; 3.permeate tank; 4.wasted sludge tank; 5.air sparger

The equations of the biological sub-model (Buzatu and Lavric, 2010) are based upon mass balances around the whole bioreactor for all wastewater components; the Monod type kinetics applies for the different substrates (Di Bella et al., 2008). The mass balances for generic soluble and insoluble substrates are given by equations (1) and (2), respectively:

$$\frac{dS_i^R}{dt} = \frac{Q^{IN} \cdot S_i^{IN} + Q^B \cdot \overline{S_i^P} - Q^W \cdot S_i^R - Q^P \cdot S_i^R}{V^R} - \sum \alpha_{S,i} \cdot \rho_{S,i}^{cons.} + \sum \beta_{S,i} \cdot \rho_{S,i}^{prod.},\ i = 1..M \quad (1)$$

$$\frac{dX_i^R}{dt} = \frac{Q^{IN} \cdot X_i^{IN} - Q^W \cdot X_i^R}{V^R} - \sum \alpha_{X,i} \cdot \rho_{X,i}^{cons.} + \sum \beta_{X,i} \cdot \rho_{X,i}^{prod.},\ i = 1..N \quad (2)$$

where M is the number of soluble species, N is the number of particulate species, α and β represent the coefficients of the reaction rates, ρ_{prod} and ρ_{cons} are the formation and consumption rates of the soluble or insoluble species present in the wastewater.

3. The efficiency of the treatment process

In our previous paper (Buzatu and Lavric, 2010) we used the global conversion of ammonia plus ammonium nitrogen to measure the system's performance. In the present paper, this conversion quantifies the performance only in conjunction with the dual-objective optimization of the semi-continuous (SC) operation mode. This way, the results at hand are easily compared to those already presented (Buzatu and Lavric, 2010).
Nevertheless, when we investigated a different operating policy, we used as first objective function the minimum between the global conversions of a) the ammonia plus ammonium nitrogen and b) the soluble biodegradable substrate. This change was triggered by the need to have a treatment process that ensures a high level of consumption for each of the two pollutants; when using conversion of ammonia plus ammonium nitrogen only, the conversion for the soluble biodegradable substrate did not reach a convenient value. In addition to this, the weighted productivity at the end of the working period was introduced as the second objective function; this way, we try to make sure the process doesn't take too much time to attain a certain minimum conversion. The productivity of a substrate, i, on a mass basis, at any time, τ, is:

$$P_i(\tau)=\frac{m_i^{IN}-m_i^{OUT}(\tau)}{m_{B,i}(\tau)\cdot\tau} \tag{3}$$

and the weighted productivity reads as:

$$\bar{P}(\tau)=\sum_i x_i^{IN}\cdot P_i(\tau) \tag{4}$$

where i is the generic substrate entering the productivity evaluation, m_i^{IN} is the quantity of substrate i in the feeding tank and reactor at the beginning of the process, m_i^{OUT} is the quantity of substrate i remained untransformed at the moment τ, $m_{B,i}$ is the quantity of bacteria that consumes the substrate i and x_i^{IN} is the initial fraction of this substrate in the mixture considered for productivity computation (the considered pollutants are the ammonia plus ammonium nitrogen and the soluble biodegradable substrate).

4. Results and discussions

The operating parameters (filtration period and air flow) of the SMBR studied have previously been optimized (Buzatu and Lavric, 2010) using the global conversion of ammonia plus ammonium nitrogen as the performance criterion; then, the mathematical model was solved using these optimal values. Since the pollutants' levels at the end of the SC operating period were still unsatisfactory, two operating strategies were tested in order to improve the removal efficiency: the discontinuous and the continuous recirculation of the permeate. The first strategy aimed to take advantage of the high concentration of microorganisms at the end of the first operating period for a supplemental treatment, while the second intended to reduce the pollutants' concentrations from the very beginning of the process. The results showed that the former was the most effective in terms of pollutant removal and operating time (Buzatu and Lavric, 2010).

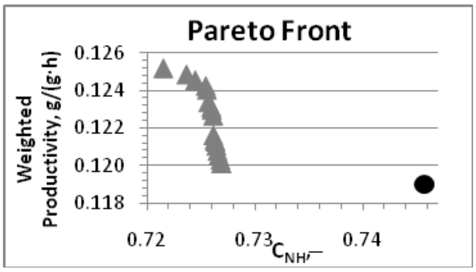

Figure 2: The Pareto front for the case without DC operation period; comparison with the point obtained with the single-objective optimization

This time a dual-objective optimization has been carried out for the original system (SC operation, no recirculation involved) using the same optimization parameters (filtration period and the air flow). The results are presented in Figure 2. As expected, a Pareto front (PF) was obtained (grey triangles) as a result of the dichotomy between the two goals – maximum conversion and minimum operating period. It can be noted that all points belonging to the PF are located to the left side (lower conversions) of the point obtained when the single-objective optimization was performed (the black dot) (Buzatu and Lavric, 2010). Even if they have higher productivities, this increase does not compensate for the loss in conversion which renders the treated water non dischargeable.

The main problem with this operating strategy is that the microorganisms have low concentrations at the beginning of the process and the pollutants leave the reactor untransformed. So, we propose a more complex operating strategy to cope with this drawback: the system is operated discontinuously till a certain concentration of microorganisms, and then the SC operation is adopted. This way, the microorganisms grow to a convenient concentration and process the pollutants to a certain extent before being evacuated through the wastage line. This strategy was optimized adding the period of discontinuous operation (DC) to the other two parameters (filtration period and air flow) and using the minimum between the global conversions of the two substrates instead of the conversion of ammonia plus ammonium nitrogen only. This change forces the system to work at high conversions for both substrates.

As shown in Figure 3, the black dots, the weighted productivity decreases almost linearly with the minimum conversion to a certain point, then an accelerated drop can be observed. This drop appears because the DC time allocated for the bioreactor reaches its upper limit during the optimization process. This prevents the system to reach even higher conversions at the expense of the weighted productivity. The grey triangles represent the PF obtained when no DC operation was involved (the same as in Figure 2). As expected, this old operating policy gives higher productivities due to its shorter working time – when the system operates SC only, it takes less time for the wastewater stored in tank (1) to pass through the bioreactor (2) (see Figure 1 for details). However, this

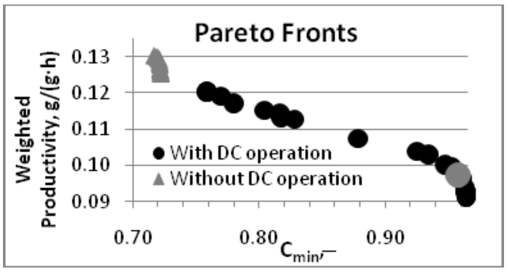

Figure 3: The Pareto front for the case with DC operation period-black dots; comparison with the previous case-grey triangles, Figure 2

small increase does not counterbalance the severe loss of the global conversion. Moreover, we must not forget that this optimization was performed using the global conversion of ammonia plus ammonium nitrogen as first objective function. Under these circumstances, the conversion of the soluble biodegradable substrate is always lower than ammonia conversion. The optimization of the new operating policy is done using the minimum of the two conversions. Therefore, the differences are even greater than shown in Figure 3.

The next step in our study was to obtain the temporal profiles for this new operating policy. For this purpose, the point from the PF closest to the optimum solution obtained for the discontinuous recirculation (i.e., the best of the two previously tested recirculation types) was chosen (Figure 3, the grey dot). Even if this point has approximately the same productivity and conversion as the DC- SC policy, the required air flow is almost 45 % lower than the air flow used in the former operating strategy, with significant operating costs benefits.

In Figure 4 the temporal profiles for the global conversions and productivities of the two substrates are shown. The goal of using a DC operating period was accomplished, as both final conversions are higher than 0.95. The conversion of ammonia (C_{NH}), however, has a constant value between the moment at which this substrate reaches a negligible concentration in the reactor (not shown here) and the moment at which the operating mode is switched to semi-continuous. In this period, the quantity of the consumed substrate is zero, since there is no ammonia in the reactor to be processed; therefore the cumulated conversion remains constant. After this point, the increase is resumed due to the reduction of the ammonia level in the feeding tank compared to its level at the beginning of the process or during the DC period, even if the terms accounting for the reactor, the permeate and the waste tanks in the conversion formula are zero. This short period is also reflected in the evolution of this substrate's productivity (P_{NH}), which experiences a slight decline. The processed quantity remains constant - the numerator in Eq. (3) -, but the time is increasing - denominator in Eq. (3) -, causing the aforementioned decrease. When the SC operation is started, the growth is resumed because the pollutant in the feeding tank is consumed and the autotrophs' (BA) concentration - denominator in Eq. (3) - decreases (not shown here) as a result of the low levels at which they are now exposed in the reactor.

The productivity of the soluble biodegradable substrate (P_S) decreases continuously

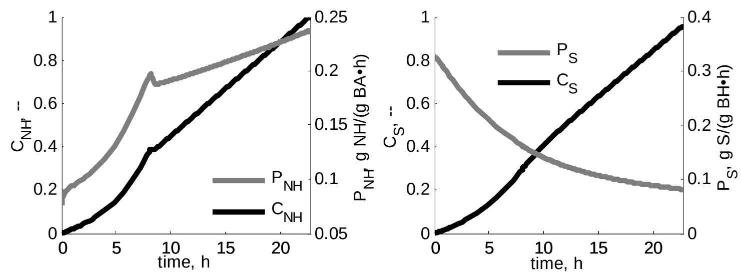

Figure 4: The temporal profiles of the two conversions and productivities

because the heterotrophs' (BH) concentration increases continuously and this growth is faster than the pollutant consumption. Since this substrate concentration does not reach a low limit in the reactor before switching to SC operation, no significant shape change can be observed in its productivity (P_S) or conversion (C_S).

5. Conclusions

A system used for wastewater treatment was optimized using a dual-objective function – global conversion of ammonia plus ammonium nitrogen and the weighted productivity. The PF displays undesirable low conversions. A new strategy was proposed then the system optimized: the DC operation of the bioreactor until the activated sludge reaches a convenient concentration, and then switch to the regular SC operation. The PF displays significantly higher conversions. A comparison made between similar operating conditions for the two policies shows 45 % lower air flow demand with the new strategy, which is the most effective of all tested so far.

Acknowledgments
Pompilia Buzatu kindly acknowledges the financial support of the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/88/1.5/S/60203.

References

Arevalo, J., Moreno, B., Perez, J. and Gomez, M. A., 2009, Applicability of the Sludge Biotic Index (SBI) for MBR activated sludge control, Journal of Hazardous Materials, 167, 784-789

Buzatu, P. and Lavric, V., 2010, Submerged Membrane Bioreactor for Wastewater Treatment: Optimal Operating Strategy, Chemical Engineering Transactions, 21, 1039-1044

Di Bella, G., Mannina, G. and Viviani, G., 2008, An integrated model for physical-biological wastewater organic removal in a submerged membrane bioreactor: Model development and parameter estimation, Journal of Membrane Science, 322, 1-12

Dialynas, E. and Diamadopoulos, E., 2009, Integration of a membrane bioreactor coupled with reverse osmosis for advanced treatment of municipal wastewater, Desalination, 238, 302-311

Meng, F., Chae, S.-R., Drews, A., Kraume, M., Shin, H.-S. and Yang, F., 2009, Recent advances in membrane bioreactors (MBRs): Membrane fouling and membrane material, Water Research, 43, 1489-1512

Schoeberl, P., Brik, M., Bertoni, M., Braun, R. and Fuchs, W., 2005, Optimization of operational parameters for a submerged membrane bioreactor treating dyehouse wastewater, Separation and Purification Technology, 44, 61-68

Teck, H. C., Loong, K. S., Sun, D. D. and Leckie, J. O., 2009, Influence of a prolonged solid retention time environment on nitrification/denitrification and sludge production in a submerged membrane bioreactor, Desalination, 245, 28-43

Zarragoitia, A., Schetrite, S., Jáuregui-Haza, U. J., Lorain, O. and Albasi, C., 2009, Computer Aided Chemical Engineering, 27, 1545-1550