ELSEVIER

Desalination 179 (2005) 109–116

DESALINATION

www.elsevier.com/locate/desal

A membrane coupled to a sequencing batch reactor for water reuse and removal of coliform bacteria

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Received 29 September 2004; accepted 22 November 2004

Abstract

Wastewater reclamation was studied by using a small biological reactor and an external filtration membrane coupled in series. Use of the membrane enhanced the quality of the effluent of the biological reactor in terms of suspended solids and presence of indicator bacteria. Partial removal of faecal coliforms and *Escherichia coli* was observed in the effluent of a sequencing batch reactor (SBR) previous to filtration by the membrane. Use of the membrane ensured full removal of the indicator bacteria in the final permeate. More than 95% of organic matter, suspended solids, and coliform bacteria were successfully removed. The operation and behaviour of internal submerged membranes in two different bioreactors was an additional objective. For this reason, two configurations—a membrane coupled to a SBR (MSBR) and a continuous membrane bioreactor (MBR)—were used during the study. Particular attention was focused on fouling and hydraulic conditions in the membranes. Fouling could be reduced by maintaining turbulent conditions and by operating at sub-critical flux.

Keywords: Coliform bacteria; Membrane; Reuse; Sequencing batch reactor; Wastewater

1. Introduction

Existing municipal wastewater treatment plants have to meet increasingly stringent discharge limits for BOD_5, COD and SS. New regulations also impose nitrogen and phosphorus discharge levels or removal efficiencies and bacteriological quality, especially in environmentally sensitive areas. To abide by the new regulations, standards plant up-grading is often necessary.

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Presented at the conference on Membranes in Drinking and Industrial Water Production, L'Aquila, Italy, 15–17 November 2004. Organized by the European Desalination Society.

doi:10.1016/j.desal.2004.11.059

The optimisation of existing conventional processes and facilities, while representing the first logical response to meet this challenge, will be limited to the maximum efficiency technically and economically achievable by such conventional processes (limits often associated with the performance of the secondary clarifier). Innovative up-grading schemes for sewage treatment plants are emerging in response to this challenge. The use of immersed membranes as biomass separators in secondary treatment systems is an approach which holds interesting promises in this context; and in the case of a sequencing batch reactor (SBR), the use of an external membrane module coupled to the system could be suitable technology to achieve high-quality effluents [1].

SBR processes offer several advantages over other types of activated sludge reactors. In particular, the hallmark of SBR design is its inherent flexibility of cyclic phasing. The cycle format can be easily modified at any time to offset changes in process conditions, influent characteristics or treatment objectives. However, a critical aspect of SBR technology is poor clarification associated with effluent turbidity.

Combining a membrane process with SBR may provide advantages for both processes. The use of membranes can reduce the SBR cycle length since the settling phase is no longer required and clear water can be extracted during the reaction time [2]. The membrane process completely removes coliform bacteria and suspended solids, thus providing a higher quality effluent with respect to conventional processes. The application of membrane filtration has some advantages compared to traditional disinfection techniques, such as avoiding the formation of by-products.

A membrane separation process was coupled to a SBR to obtain water suitable for reuse. The main objective of this study was the evaluation of the applicability of the coupled SBR + a membrane system for the removal of faecal coliforms and *Escherichia coli*.

A reduction of the microbial load is necessary for water reuse in agriculture, as stated in the Italian legislation, which indicates a limit of 10 CFU/100mL for *E. coli* [3]. Membrane bioreactors present a means of biologically treating high COD or BOD wastewaters, but, like other membrane processes, are constrained by their tendency to foul. Fouling can be reduced by maintaining turbulent conditions, operating at sub-critical flux and selection of a suitable fouling-resistant membrane material [4].

The performance of two configurations, (1) a membrane coupled to a SBR (MSBR) and (2) a membrane continuous bioreactor (MBR), was studied with particular attention paid to the fouling and the hydraulic conditions.

2. Materials and methods

2.1. Experimental set-up

The laboratory-scale SBR was a cylindrical vessel with a working volume of 20 L. Peristaltic pumps were used for feed, discharge of the effluent and biomass purging. During the oxic phase, oxygen was supplied by an air blower (mass transfer coefficient, K_La = 0.2 min^{-1}). Mechanical mixing was supplied during both the oxic and anoxic phases. Temperature was maintained at 25°C by a thermostatic bath, while pH varied between 7.2 and 8.3. The actions of the pumps, aeration system and stirrer were controlled by four timers.

The reactor was equipped with a data acquisition system, multiple analyse reprogrammable titration analyser (MARTINA) [5], Spes scrl, Fabriano (AN) with the following probes:

- ORP probe (InLab 501, Mettler Toledo, Greifensee, Swithzerland)
- Dissolved oxygen probe (COS3S, Endress Hauser, Reinach, Switzerland)
- pH electrode (InLab 412, Mettler Toledo, Greifensee, Switzerland)
- Temperature probe (Pt100, TRM).

Data were acquired each 20 s. After settling and decanted, the SBR effluent was pumped to the membrane reactor for filtration with a hollow-fibre membrane module, ZW-1 (Zenon) with a pore size of 0.2 μm and an effective surface area of 0.093 m^2. The external diameter of each fibre was 1.8 mm while the internal diameter was 0.5–1 mm. The membrane was 50 mm wide and 175 mm long.

The ZW-1 module comes with an extended aeration tube that is also used to attach the module to the support bracket to hold it in place vertically. It has two holes on the top header: one for the permeate and one for pressure measurement. The permeate is drawn only from the top header. The central aeration tube supplies air to the bottom header where air diffusers are located. The ZW-1 module was connected to a vacuometer in order to measure the transmembrane pressure (TMP).

2.2. Strategy of operation

The reactor was operated with a HRT of 1.25 d in cycles of 6 h including a reaction phase of 300 min (90 anoxic, 210 aerobic), a settling period of 37 min and an effluent withdrawal period of 23 min.

Initially, the reactor was fed with a synthetic medium made of peptone, meat extract and salts (COD = 600 mg/L, N_{tot} = 75 mg/L, P_{tot} = 11.4 mg/L) (Table 1) with the trace solution according to Larsen and Harremoes [6]. The microbial inoculum came from a primary treated urban wastewater (Table 2) which was added to the synthetic feed (1/10 v/v).

Finally, some cycles were performed feeding urban wastewater to assess membrane efficiency on undiluted real wastewater.

2.3. Analytical methods

The pH, nitrate, ammonia, total nitrogen, volatile and total suspended solids (VSS and TSS), and COD were determined according to Standard Methods [7].

Faecal coliforms and *E. coli* were measured with the membrane filtration technique using C-EC agar, and the results are expressed as coliform forming units (CFU) in 100 mL/sample [8]. *E. coli* was enumerated from faecal coliforms by using a wood lamp.

Table 1
Composition of synthetic medium used to feed the SBR

Compounds	Values (g/L)
Peptone	0.457
Meat extract	0.236
NaCl	0.015
$CaCl_2 \cdot 2H_2O$	0.012
$MgSO_4 \cdot 7H_2O$	0.0045
K_2HPO_4	0.06

Table 2
Average composition of the Pero urban wastewater treatment plant in Milano

Compounds	Values (mg/L, except pH)
pH	7.73
TSS	86.79
BOD_5	99.77
COD	266.74
N_{tot}	32.36
$N\text{-}NH_4^+$	18.77
Ptot	3.79
Al	1.56
Cr	0.1
Fe	0.94
Pb	0.01

2.4. Determination of critical and maximum flux

Critical and maximum fluxes were determined by monitoring the TMP according to the procedure suggested by Kwon et al. [9].

2.5. Hydraulic conditions

Two configurations were compared: (1) a ZW-1 membrane coupled to a SBR (MSBR) and (2) a membrane bioreactor (MBR). Two laboratory-scale SBRs with a total volume of 5 L and a working volume of 4 L were used. In the first configuration, the system was operated with the same reaction phase as the 20 L SBR described above, but no sedimentation was performed since the membrane module was used for effluent extraction. The second reactor was operated as a MBR constantly aerated and with constant permeate extraction.

3. Results and discussion

3.1. Membrane-coupled SBR

During the entire experimental period, the SBR effluent was characterised by: COD< 50 mg/L, TKN< 5 mg N/l, NO_3^- <20 mg N/L. The COD removal efficiency in the SBR was 95%. The concentration of suspended solids in the effluent of the SBR was lower than 50 mg TSS/L and a complete removal was achieved after filtration with the ZW-1 membrane module.

The operational period can be divided into two periods according to the type of SBR feeding:

1. 10% urban wastewater in the feed (50 days of operation). In the SBR influent, faecal coliforms were in the range 3.7×10^4–1.0×10^5 CFU/100 mL and 3.7×10^4–1×10^5 CFU/100 mL as *E. coli*. In the effluent of the SBR, faecal coliforms were around 4.0×10^3–1.0×10^5 CFU/100 mL and *E. coli* around 3.0×10^2–4.3×10^4 CFU/100 mL, while no faecal coliforms nor *E. coli* were found in the permeate (Figs. 1 and 2).

2. 100% urban wastewater in the feeding (10 days of operation). Faecal coliforms were in the range 1.2×10^6–1.8×10^6 CFU/100 mL in the SBR influent and 4.0×10^3–1×10^4 CFU/100 mL in the SBR effluent (Fig. 3), while *E. coli* were 1.0×10^6–1.4×10^6 CFU/100mL and 2.0×10^3–4.1×10^3 CFU/100mL for the influent and effluent, respectively (Fig. 4). Neither faecal coliforms nor *E. coli* were found in the permeate.

These results are in agreement with those reported in previous attempts to apply membrane filtration on raw/biologically treated domestic sewage. Ueda and Hata [10] operated a MBR with gravitational filtration using a pilot-scale plant and raw domestic wastewater. Treated water was filtered through flat microfiltration membrane modules (polyethylene: pore size 0.4 μm), and quality of the treated water indicated that the removal of organic matter and suspended solids was quite successful. Coliform bacteria were detected in the treated water at trace levels, possibly due to the contamination of pipelines for the treated water. Nevertheless, a 6-log removal of coliform bacteria was achieved.

Other studies [11] have reported that more than 90% of organic matter, suspended solids, and coliform bacteria were successfully removed from a domestic sewage using a hollow-fibre membrane. Moreover, an activated sludge system with cross-flow membrane filtration was found to remove bacteria and particular solids to concentrations fitting reuse requirements. High COD and N removal efficiencies (about 98%) were also achieved [12].

3.2. Determination of critical flux and maximum flux

In order to obtain the optimal conditions of operation of the membrane, the critical flux and maximum flux were determined for different VSS concentrations and are reported in Fig. 5. At VSS concentrations in the range 0 and 2.5 g VSS/L, the critical flux was not reached at the maximum flow tested [35 L/(m^2·h)] as the TMP was maintained constant. In the case of VSS concentrations of 5.0–7.5 g VSS/L, the critical flux was reached at 20–25 $L\cdot h^{-1}\cdot m^{-2}$. Higher values of the TMP increased with the operation time. The value of

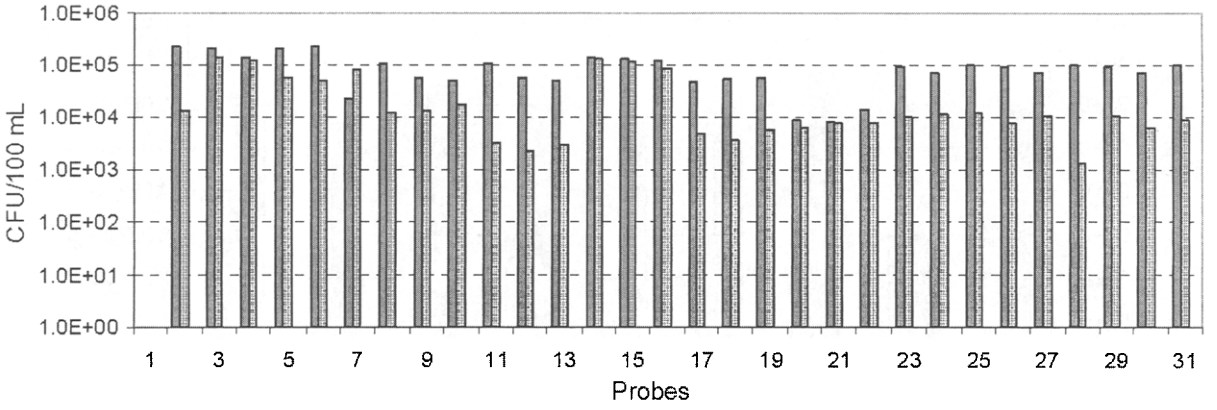

Fig. 1. Evolution of the faecal coliforms in the system with 10% urban wastewater in the feed (■ influent SBR, □ effluent SBR previous to filtration).

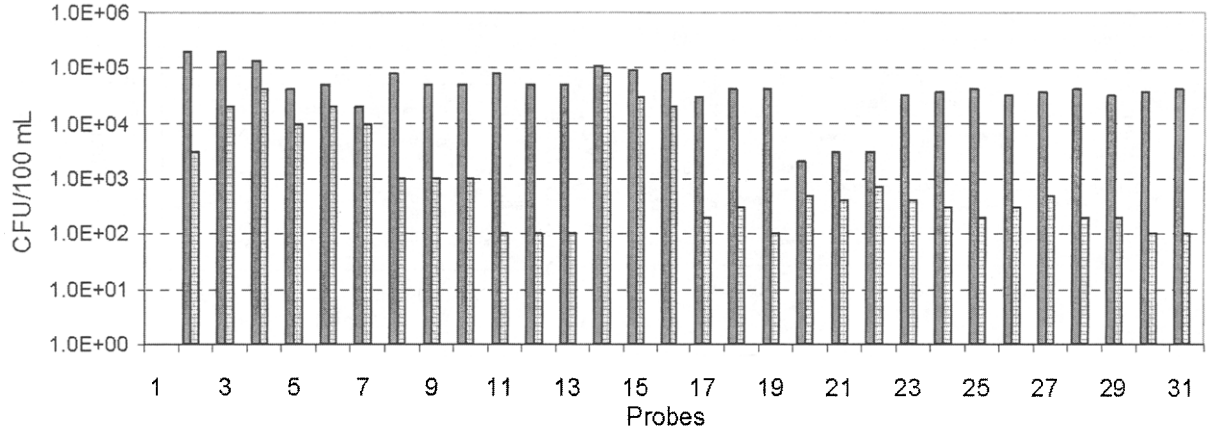

Fig. 2. Evolution of the *E. coli* in the system with 10% urban wastewater in the feed (■ influent SBR, □ effluent SBR previous to the filtration).

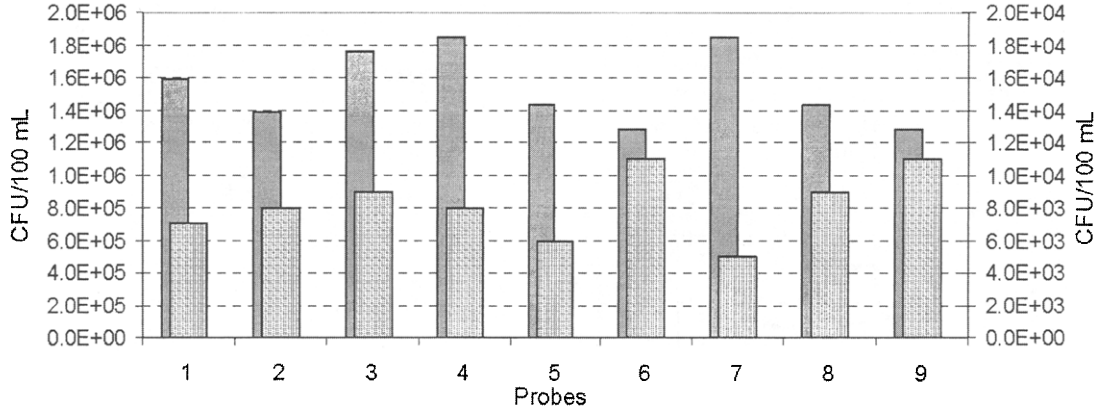

Fig. 3. Evolution of the faecal coliforms in the system with 100% urban wastewater in the feed (■ influent SBR, left axis; □ effluent SBR previously to the filtration, right axis).

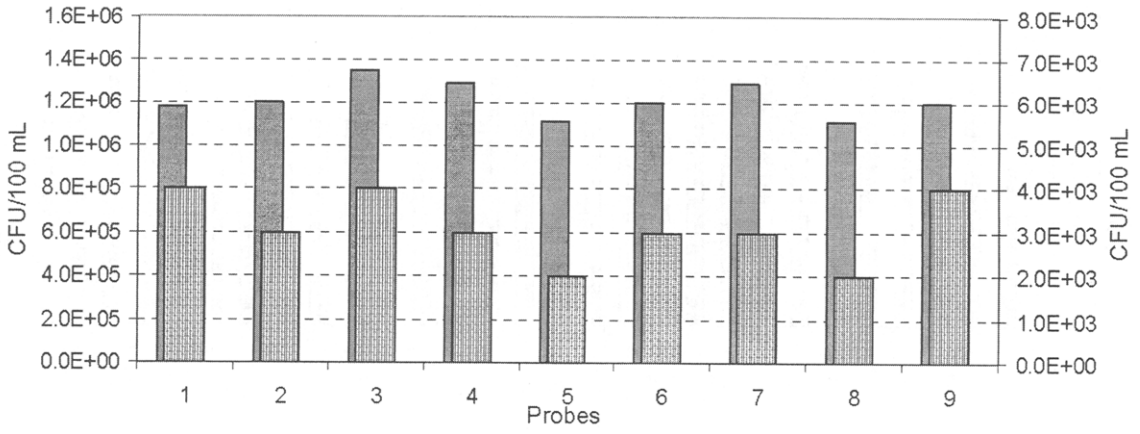

Fig. 4. Evolution of the *E. coli* in the system with 100% urban wastewater in the feed (■ influent SBR, left axis; □ effluent SBR previous to the filtration, right axis).

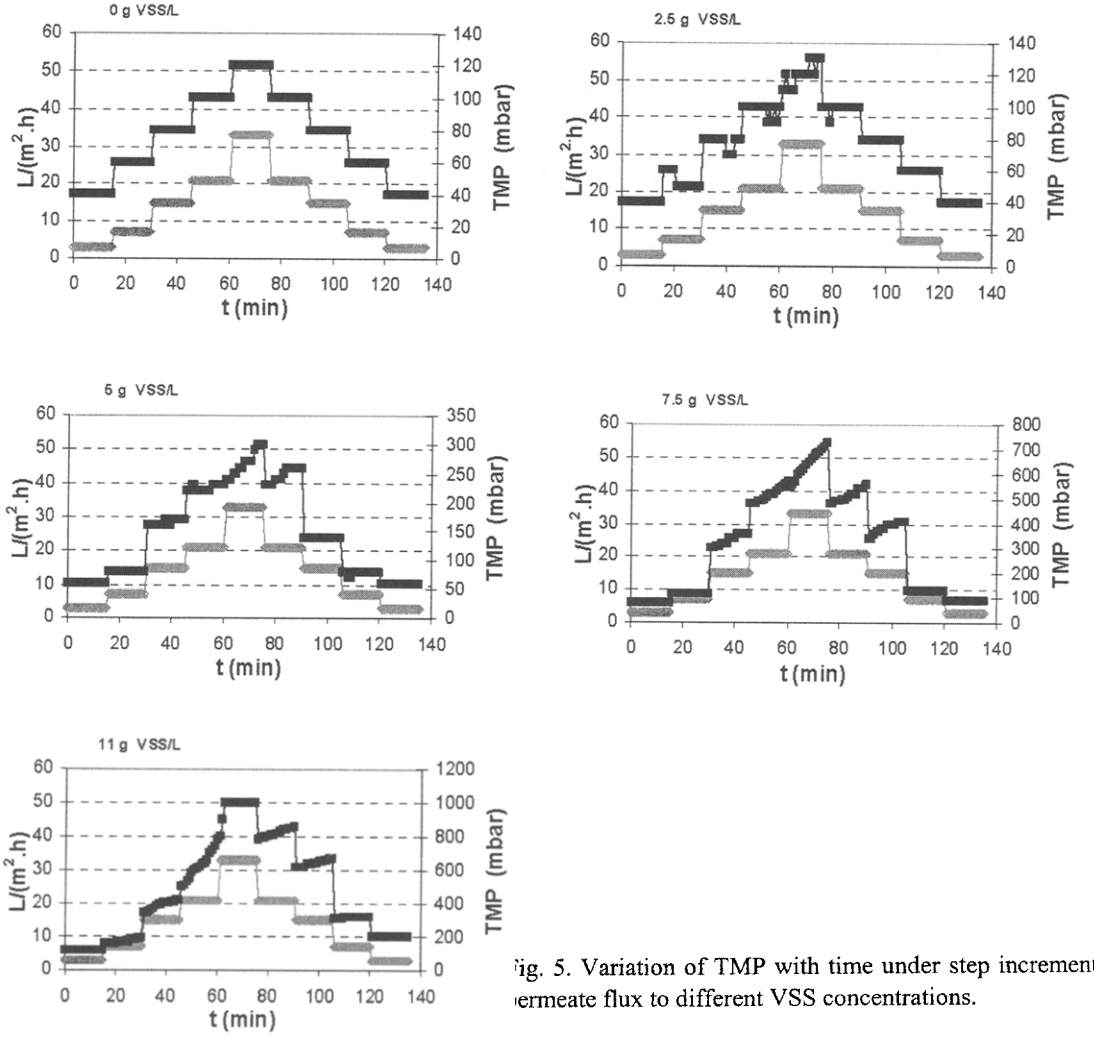

Fig. 5. Variation of TMP with time under step increments of permeate flux to different VSS concentrations.

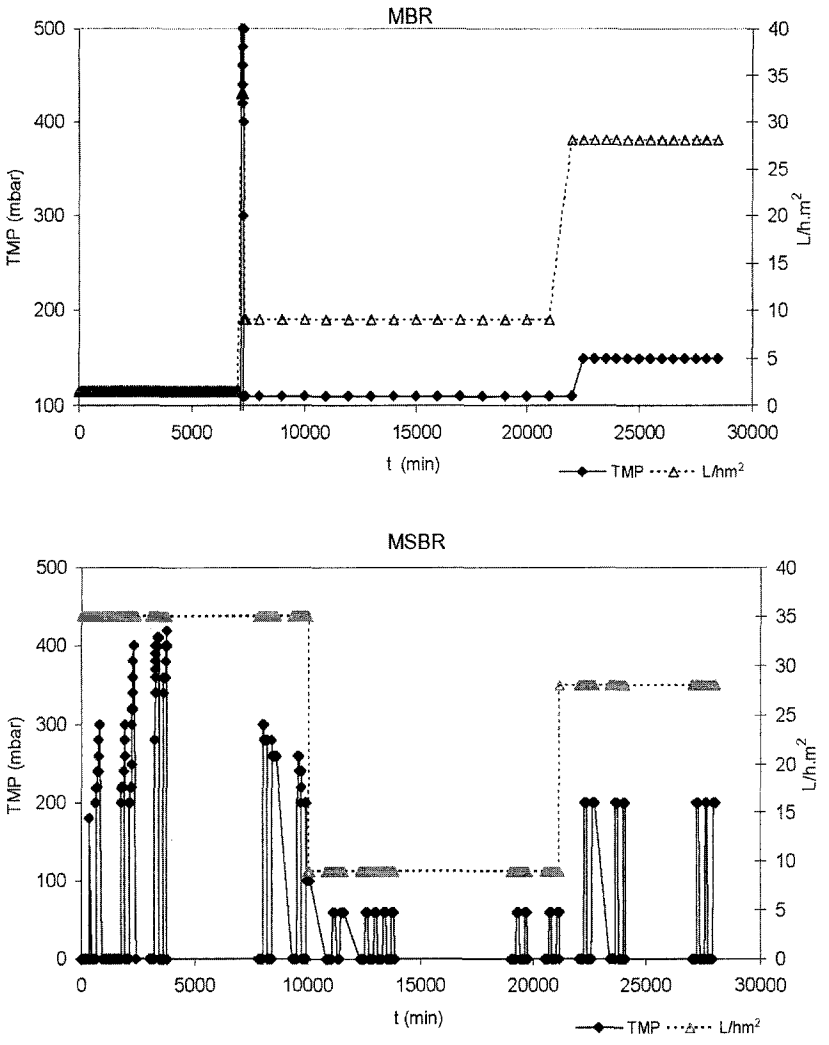

Fig. 6. Operation of the MSBR and MBR.

critical and maximum flux was below 10 L/(m^2·h) at a VSS concentration of 11 g VSS/L. These data should be considered as comparative and not absolute values, as, of course, the laboratory-scale conditions are not comparable to full-scale conditions where the control of fouling can be optimised.

3.3. Two configurations

Both configurations—the MSBR with intermittent permeate extraction and the MBR with continuous permeate extraction—were used to monitor their performances at an equal daily flow permeate extraction. The two reactors were inoculated with 2.5 g VSS/L from 20L SBR. The main operational stages of the reactors were (Fig. 6):

1. First period (0–10,000 min). Although the operation of the MSBR was satisfactory during the first cycles (TMP was maintained constant around 150 mbar) to a flux of 35 L/(m^2·h) with a withdrawal time of 1 h/d, after 4,000 min the TMP was increased along the withdrawal time

and subsequently fouling was reached. Chemical cleaning of the membrane was necessary. The MBR was operated continually with a flow of 1.5 L/(m^2·h) and TMP was maintained constant (<50 mbar) during the entire operation, except when the flow was increased drastically.

2. Second period (10,000–20,000 min). The withdrawal time was increased to 4 h/d, decreasing the flux to 8.5 L/(m^2·h) and the operation of the MSBR was stable (TMP = 70 mbar). The MBR was also stable at the same flux.

3. Third period (20,000–30,000 min). The withdrawal time was maintained and the flow was increased to 28 L/(m^2·h) in the MSBR and MBR. The operation of the membranes was satisfactory. Optimal conditions were reached to operate the MSBR and the MBR.

4. Conclusions

Results demonstrated that the removal efficiency of both bacteria and suspended solids by membrane filtration was 100%, suggesting that the experimented compact system (SBR + membrane filtration) could produce an effluent suitable for reuse in agriculture and could be a suitable technology for rural communities. The membrane process coupled with a SBR not only replaces the sedimentation period in the operation of a SBR but also serves as an advanced treatment unit for coliform bacteria and suspended solids, which cannot be removed completely by conventional processes.

The operation of two configurations, a membrane coupled to a SBR and a MBR, were satisfactory to operate the system to the optimal hydraulic conditions.

Acknowledgements

This work was funded by the Integrated Action Italy–Spain (Ref. HI 2002-0138), Xunta de Galicia (PGIDITOPXIC20906PN) and the Spanish Ministry of Science and Technology (Oxanamon Project PPQ-2002-00071). The SBR operation was funded by the EC (EOLI project ICA4-CT-2002-10012).

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