DESALINATION

ELSEVIER Desalination 113 (1997) 189–196

Immersed membrane activated sludge for the reuse of municipal wastewater

Pierre Côté[a*], Hervé Buisson[a], Charles Pound[b], Greg Arakaki[b]

[a]*Anjou Recherche, Chemin de la Digue, BP 76, 78603 Maisons-Laffitte Cedex, France*
Tel. +33 1 34-93-31-31; Fax +33 1 34-93-31-41
[b]*Metcalf and Eddy, 701B Street, Suite 1100, San Diego, CA 92101, USA*
Tel. +1 (619) 233-7855 Fax +1 (619) 233-7861

Received 15 August 1997; accepted 21 August 1997

Abstract

The results of two pilot studies of an immersed membrane activated sludge process are presented. This process involves coupling a bioreactor with effluent separation by microfiltration hollow fibres immersed directly in the bioreactor. The two pilot studies were conducted at Valley Sanitary District, Indio, California, for 5 months and in Maisons-Laffitte, France, for 1 year. The objectives were to demonstrate the process with high biomass concentration (between 5 and 15 g/l) and sludge ages of 10 and 50 days. The process provided a high degree of treatment in terms of suspended solids (100%) and organic matter (>96% for COD). When operated in nitrification-denitrification mode, 99% ammonia and 80% total nitrogen removal were obtained. Better than 6 log removal of total coliforms and better than approximately 4 log removal of naturally occuring bacteriophages were observed. The effluent was suitably pretreated for reverse osmosis in terms of fouling potential. Sludge production was 0.25 kg dry solids/kg of COD/day, about 50% smaller than a conventional activated sludge process. It was demonstrated that the immersed membrane filtration system was able to operate without chemical cleaning or handling of the membrane modules and had an energy requirement for filtration of only 0.3 kWh/m^3 of wastewater treated. The process provides the benefits of membrane filtration (quality, safety, compactness) without its usual disadvantages (high energy consumption, requirements for frequent cleaning). These features make it a "High Tech Rustic Process".

Keywords: Water reuse; Activated sludge; Immersed membranes; Microfiltration; Membrane bioreactor; Reverse osmosis

*Corresponding author.

PII S0011-9164(97)00128-8

1. Introduction

With the increased worldwide pressure on water resources, effluent recycle and reuse are developing for irrigation and agriculture as well as for indirect and even direct potable water supply. Until recently, the approach has consisted of providing advanced treatment to a secondary treated effluent to meet the standards for reuse. For irrigation this treatment complement may be limited to filtration and disinfection. For groundwater recharge, the treatment complement normally involves reverse osmosis (RO) and may become rather complex, as illustrated in Fig. 1a, which shows the treatment train for Water Factory 21 in Orange County (USA). This train is based on a high-rate activated sludge process to remove the bulk of suspended solids and organic matter, followed by lime softening, sedimentation and sand filtration to pre-treat the effluent for RO. A cellulose acetate RO membrane is used for its resistance to fouling. In this train, large volumes of primary, biological and chemical sludges are produced.

A simplified train actually under evaluation at demonstration-scale at Water Factory 21 consists in replacing the physical-chemical pre-treatment to RO by microfiltration or ultrafiltration (Fig. 1b). This improved pre-treatment allows the use of thin-film composite (TFC) RO membranes which offer better rejection of dissolved organic matter at lower pressure. In this train, the

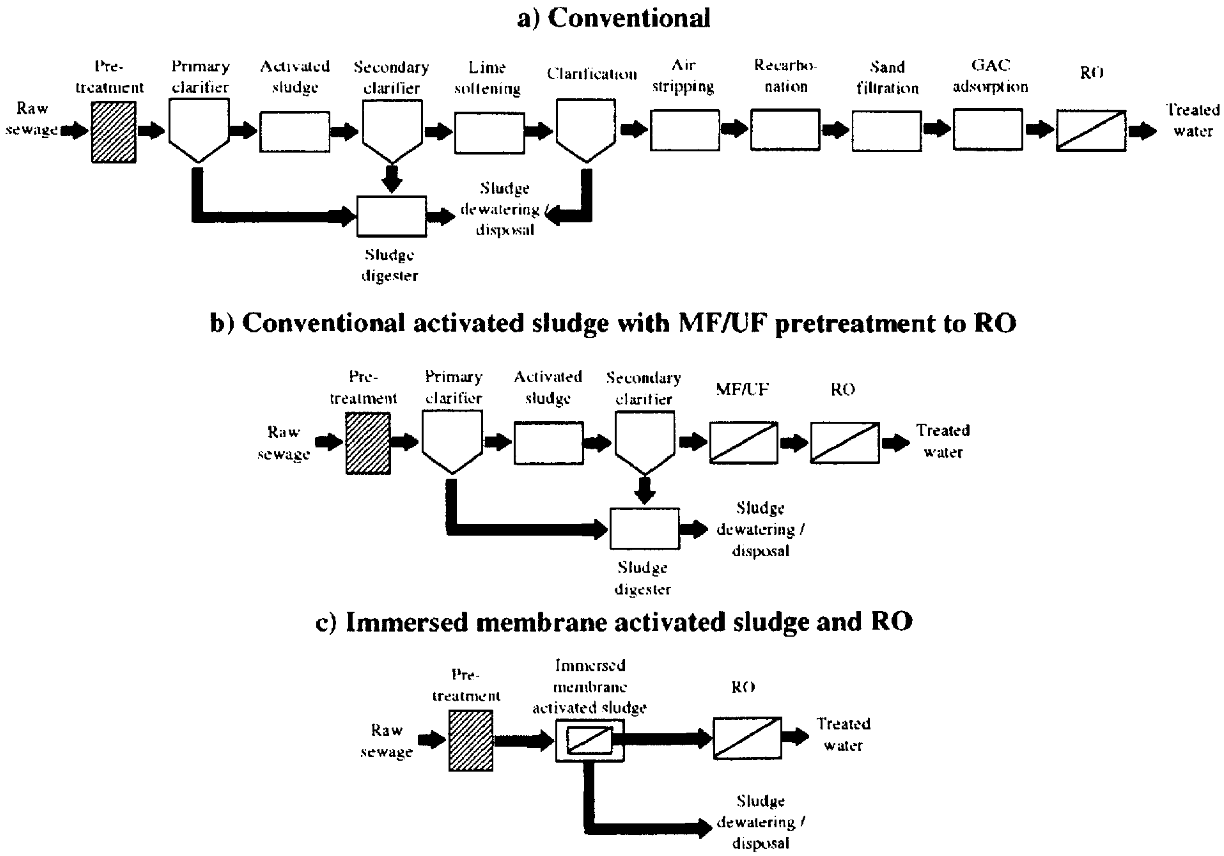

Fig. 1. Evolution of water reclamation treatment trains.

production of chemical sludge is eliminated, but the backwash requirements of the MF/UF membranes lead to overdesigning of the pre-treatment by 10–20%.

The simple treatment train shown in Fig. 1c provides the same overall level of treated quality water as the two trains described above. It is based on the use of a new process where activated sludge and membrane separation are integrated in a single treatment step. The membranes in this process replace the secondary clarifier of a conventional system. The immersed membrane activated sludge process allows the treating of raw wastewater after simple screening, with a high biomass concentration and a long sludge residence time. This results in the elimination of liquid side-streams (sand and/or membrane filter backwash), significant reduction of sludge production and improved pre-treated water quality for RO.

In this paper, the immersed membrane activated sludge process is described and the results of two pilot studies are presented.

2. Immersed membrane activated sludge

Several immersed membrane activated sludge systems based on the principle illustrated in Fig. 2 have been described in the literature [1–6]. Immersed membrane activated sludge systems

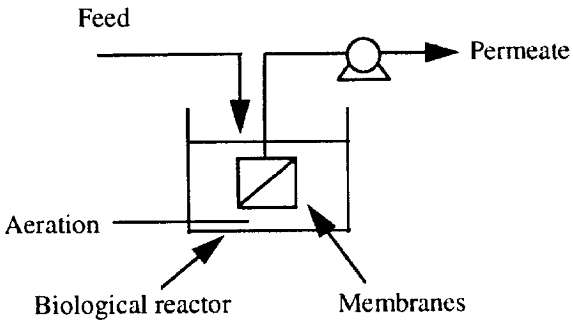

Fig. 2. Principle of the immersed membranes activated sludge process.

use shell-less capillary or flat sheet membranes. Their common features are: (1) microfiltration membranes with pore sizes in the range of between 0.1 to 0.4 μm, (2) direct immersion into the reactor where the biological treatment takes place, (3) operation in outside-in filtration mode under negative pressure, and (4) renewal of the biomass to be filtered by airlift-induced circulation.

The coupling of membranes with activated sludge offers true synergy. Its most important feature is the safety against treated water quality degradation and biomass loss offered by the membrane barrier; with conventional activated sludge, process upsets are caused by toxics in the influent, mass or hydraulic loading variations, and sludge bulking. The process can also be run at long sludge ages (>20 d) to allow the development of slow-growing microorganisms which results in better removal of nitrogen compounds and refractory organic matter; long sludge ages are not possible with conventional activated systems because they produce sludges that do not settle well. Finally, the use of membranes makes the process very compact, eliminating primary and secondary sedimentation, sludge digestion, and significantly down-sized aeration tanks (biomass concentration of 15–20 g/l are used).

In the immersed membranes activated sludge process, membranes are used extensively, at low pressure and below critical flux, where fouling is minimal [7,8]. This ensures simple, reliable and low-cost operation.

3. Pilot studies

Two pilot studies were conducted: one by Metcalf & Eddy at Valley Sanitary District (VSD), Indio, California, and the other by Anjou Recherche at its Research Centre in Maisons-Laffitte (CRML), France.

The VSD study was run between September 1996 and January 1997 on screened/degritted raw

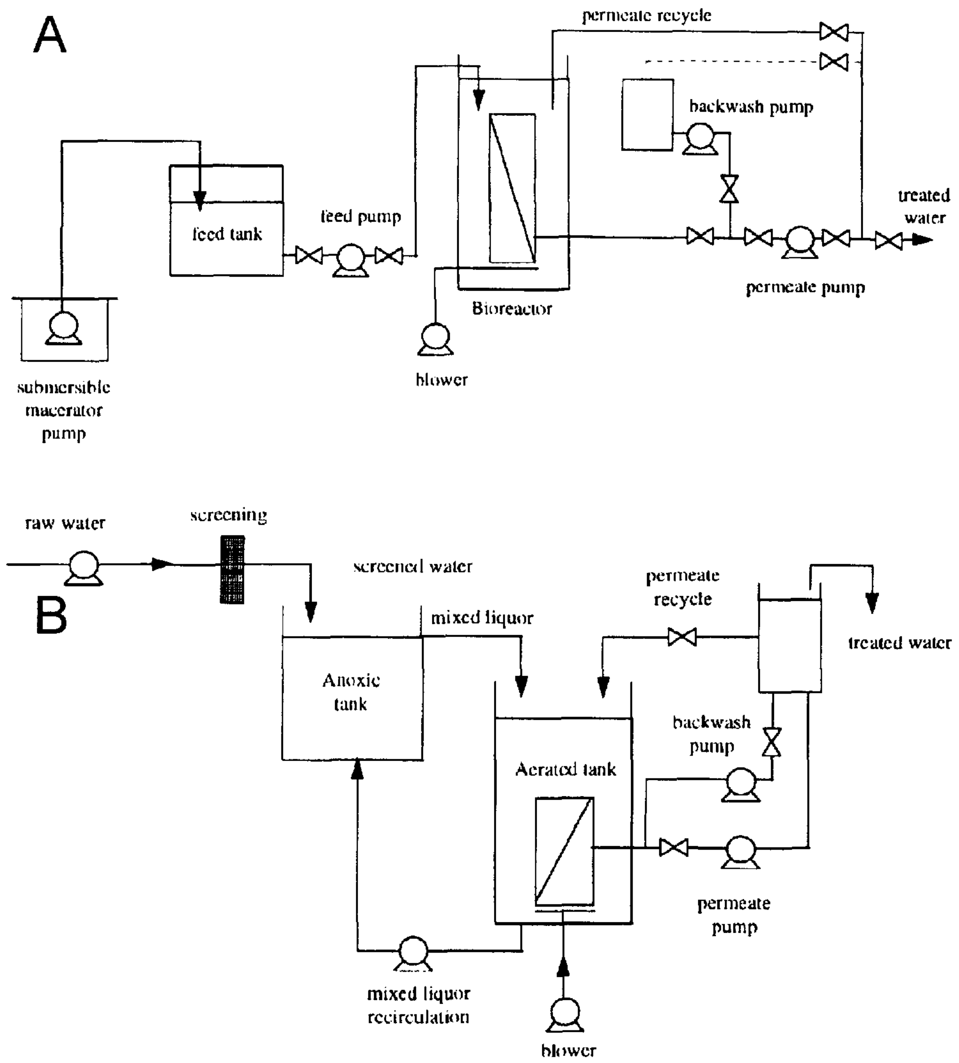

Fig. 3. Pilot plants used in the studied. A: Valley Sanitary District. B: Maisons-Laffittee Research Centre.

wastewater. The objectives of the study were to demonstrate that the process can meet California Title 22 criteria for reclaimed water with a 2-h retention time. During the course of the study, the process was evaluated with mixed liquor suspended solids (MLSS) varying between 5 and 15 g/l which corresponded to sludge retention time (SRT) of between 5 to 10 days. The mixed liquor temperature varied between 26 to 33 °C.

The CRML study lasted 1 year, between May 1995 and May 1996, and was run on raw wastewater after 1 mm screening. The objectives of the study were to determine the efficacy of biological treatment and filtration for a sludge age of 50 days and a MLSS of 15 g/l, which corresponded to a hydraulic retention time of 9 h. The mixed liquor temperature varied between 17 to 21 °C.

The pilot-plant used at Valley Sanitary District consisted of a single aerated tank as illustrated in Fig. 3a. The pilot-plant at Maisons-Laffitte was equipped with two tanks for nitrification/

denitrification as illustrated in Fig. 3b. Both units were equipped with a system which allowed recycling part of the permeate to the aeration tank in order to decouple the study of membrane flux from the process hydraulic retention time.

Both pilot units were equipped with the ZW-150 ZeeWeed® membrane from Zenon Environmental Inc., Burlington, Canada; there were two modules in the VSD pilot plant and one in the CRML pilot plant.

ZeeWeed® is a shell-less hollow fibre membrane with a nominal molecular weight cut-off of 200,000 Dalton. The fibres are mounted on a 1.83 m long, 0.5 m wide frame, with permeate extraction from bottom and top headers. The membranes are continuously aerated at their base for the purpose of renewing the biomass to be filtered and agitating the hollow fibres. The hollow fibre can be backwashed with permeate.

4. Results and discussion

4.1. Treatment results

A summary of the analytical results is presented in Table 1. Both studies showed essentially total removal of particulate matter, with permeate values below detection level for suspended solids, and average turbidities of 0.14 and 0.24, respectively, for the VSD and CRML studies.

Organic matter removal was very high, with total removal of BOD_5, and permeate COD values of 16 and 10 mg/l, respectively, for the VSD and CRML studies. These results can be compared with the performance of conventional biological processes operated on both sites (activated sludge at VSD, biofilters at CRML) which give effluent COD of between 40 and 50 mg/l. The difference is attributed, of course, to the removal of particulate and colloidal solids, but also to better degradation of refractory compounds by the confined biomass.

Good nitrification was observed in the VSD study with TKN and ammonia removal of 80% even though the sludge age (5–10 d) and hydraulic retention time (2 h) were very low. The variability of the wastewater and the small number of samples taken did not permit a complete nitrogen balance on this study.

Nitrogen removal was much better in the CRML study which was operated with a long sludge age (50 d) and with nitrification and denitrification stages. Nitrification was essentially complete with removal of 99% of ammonia. Total nitrogen removal averaged 80%, which corresponds to the theoretical limit for a sludge recirculation rate of 300%.

Phosphorus was not monitored in the VSD study. Removal of 15% was observed in the CRML study, essentially accounted for by biomass synthesis. Phosphorus removal can easily be implemented in this process by co-precipitation by iron or aluminium salts added directly in the aeration tank, as has been reported elsewhere [1,4].

Bacteriological parameters were monitored in both studies. Between 6 and 7 log removal of total coliform were observed in both studies. In the CRML study, it was demonstrated that bacterium regrowth may take place on the permeate side of the membrane. For that reason, the permeate circuit was disinfected with a 200 mg/l sodium hypochlorite solution prepared in the permeate storage tank. This disinfection was done once per week by recirculating the chlorine solution on the permeate side of the membrane for 15 min. This resulted in a small amount of chlorine permeation in the activated sludge tank with no visible effect on the biomass.

Although the membrane cut-off is higher than the size of viruses and phages, better than 4.5 and 3.8 log removal of naturally occuring bacteriophages were observed for the VSD and CRML studies, respectively. This result is attributed to the presence of large concentrations of suspended solids to which the phages attach in the bioreactors.

Sludge production was not monitored in the VSD study. In the CRML study, sludge

Table 1
Summary of the pilot study results

Parameter	VSD study				CRML study			
	No. of analyses	Feed	Permeate	Reduction	No. of analyses	Feed	Permeate	Reduction
TSS, mg/l	42	118	ND	>99%	43	120	ND	>99%
Turbidity, NTU		—	0.14	—	41	148	0.24	98.8%
COD, mg/l	40	356	16	96%	44	482	10	98%
BOD, mg/l	3	187	<5	>97%	3	220	<5	>98%
Ammonia-N, mg/l	12	28	5.6	80%	44	39	0.4	99%
TkN-N, mg/l	12	39	7.6	81%	32	54	2.0	96%
Nitrate-N, mg/l	21	—	26	—		—	9.9	—
Total-N, mg/l	12	42	27	36%		54	11.0	80%
Phosphorus, mg/l	—	—	—	—	32	9.2	8.1	15%
Total coliform, CFU/100 ml	21	5.6×10^7	20	6.4 log	12	5.9×10^7	43	6.1 log
Bacteriophages PFU/10 ml	21	3.7×10^4	—	>4.5 log	2	1.48×10^4	—	> 3.8 log

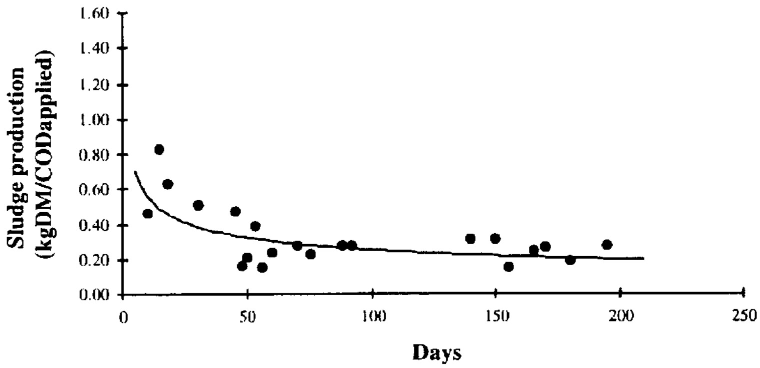

Fig. 4. Evolution of sludge production over time in the CRML study.

production decreased with time to a relatively stable level after about 100 days at a value of about 0.25 kgSS/kgCOD removed (Fig. 4). This sludge production is about 50% less than that of an extended aeration activated sludge process.

In the CRML study, the silt density index (SDI) was monitored to evaluate the suitability of the process as an RO pretreatment. The SDI averaged 1.4 and was always below 2.

4.2. Hydraulic results

The immersed membrane filtration system was designed to meet three basic operating objectives: (1) avoid chemical cleaning or handling of the membrane modules, (2) absorb flow variations, and (3) minimize energy consumption. Each will be examined in this section.

The operating conditions of the membrane filtration system in the two pilot studies are summarized in Table 2. Both membranes were used at a low transmembrane pressure of about 20 kPa, which corresponded to average instantaneous fluxes of 35 and 25 $l/m^2/h$ for the VSD and CRML studies, respectively. The better performance observed at VSD can be attributed to a higher membrane air flow rate, and to a biomass warmer by about 10 °C.

In the VSD study, the membranes were backwashed four times per hour for 30 s; in the CRML study, the membrane was backwashed 12 times per hour for 15 s. During these short backwashes, permeate is pumped back into the aeration tank and has to be refiltered; the hydraulic efficiency of both filtration systems was about 0.9 (ratio of net flux over instantaneous flux).

Table 2
Average immersed membrane operating conditions

	VSD study	CRML study
Instantaneous flux, $l/m^2/h$	35	25
Pressure, kPa	20	20
Air flow rate, Nm^3/h/module	12.0	8.0
Backwash frequency, min	16	5
Backwash duration, s	30	15

During the course of both studies, it was not necessary to remove the membranes from the activated sludge tank for cleaning; the following operations were sufficient to maintain stable fluxes and operating pressures: in the VSD study, an extended (15-min) permeate backwash once per week, and in CRML study, a 15-min chlorinated permeate recirculation once per week.

In both studies, the capacity of the membrane filtration systems to absorb flow variations was evaluated. In the VSD study, the membrane flux was doubled daily to 70 $l/h/m^2$ for periods of 1–2 h at a time. In the CRML study, a diurnal flow variation pattern with a peak to average ratio of 2.5 was simulated over several months. An extract of the results presented in Fig. 5 shows that the pressure and flux profiles could be precisely superimposed, an indication of the absence of fouling.

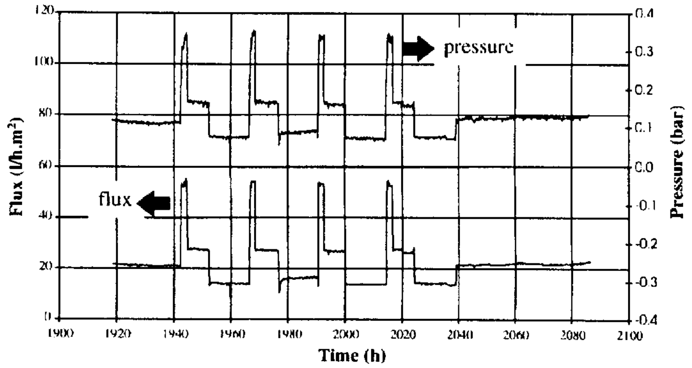

Fig. 5. Flow variation simulation in the CRML study.

Based on the operating conditions listed in Table 2, the energy consumption required for filtration was estimated to be 0.30 kWh/m^3 of wastewater treated for both systems. This figure comprises two components, the centrifugal pump for permeate extraction which accounted for 0.02 kWh/m^3 and the blower for membrane aeration which accounted for the difference, 0.28 kWh/m^3. This estimation is conservative since it does not give credit for the oxygen transfer obtained from the membrane aerators.

4. Conclusion

In conclusion, the immersed membrane activated sludge process appears well suited by itself, or in combination with RO for water reclamation and reuse.

It provides a high degree of treatment in terms of suspended solids and organic matter removal. The process can be run in a nitrification-denitrification mode to remove nitrogen compounds, and can be combined with the use of a coagulant for phosphorus removal. It provides a high level of physical disinfection and an effluent suitably pretreated to minimize fouling potential for subsequent RO treatment.

The immersed membrane activated sludge process allows the use of long sludge ages with the benefits of reduced sludge production (about 50% when compared to a conventional activated sludge process) and a simplification of the sludge treatment line.

The process provides the benefits of membrane filtration (quality, safety, compactness) without its usual disadvantages (high energy consumption, requirements for frequent cleaning). These features make it a "High Tech Rustic Process".

References

[1] H. Buisson, P. Côté, M. Praderie and H. Paillard, The use of immersed membranes for upgrading wastewater treatment plants, in: Proc., IAWQ Conference, Upgrading of Water and Wastewater System, Kalmar, 1997.

[2] S. Churchouse, Operating experiences with the Kubota submerged membrane activated sludge process, in: Proc., 1st International Meeting on Membrane Bioreactors for Wastewater Treatment, Cranfield University, 1997.

[3] H. Ishida et al., in: Second International Conference on Advances in Water and Effluent Treatment. BHR Group Series, No. 8, 1993, pp.321–330.

[4] D. Mourato, H. Behmann and G. McGinn, The Zenogem® process for municipal sewage treatment plant upgrades, in: Proc., WEF Technical Program, Dallas Convention Centre, Texas, USA, 1996.

[5] T. Ueda, K. Hata, Y. Kikuoka and O. Seino, Wat. Res., 31(3) (1997) 489.

[6] K. Yamamoto, H. Hiasa, T. Mahmood and T. Matsuo, Wat. Sci. Tech., 21(1) (1989) 43.

[7] S.S. Madaeni, A.G. Fane, and D.E. Wiley, Factors influencing critical flux in membrane filtration of biomass, in: Proc., IMSTEC'96, International Membrane Science and Technology Conference, 1996.

[8] J.A. Howell, J. Membr. Sci., 107 (1995) 165.