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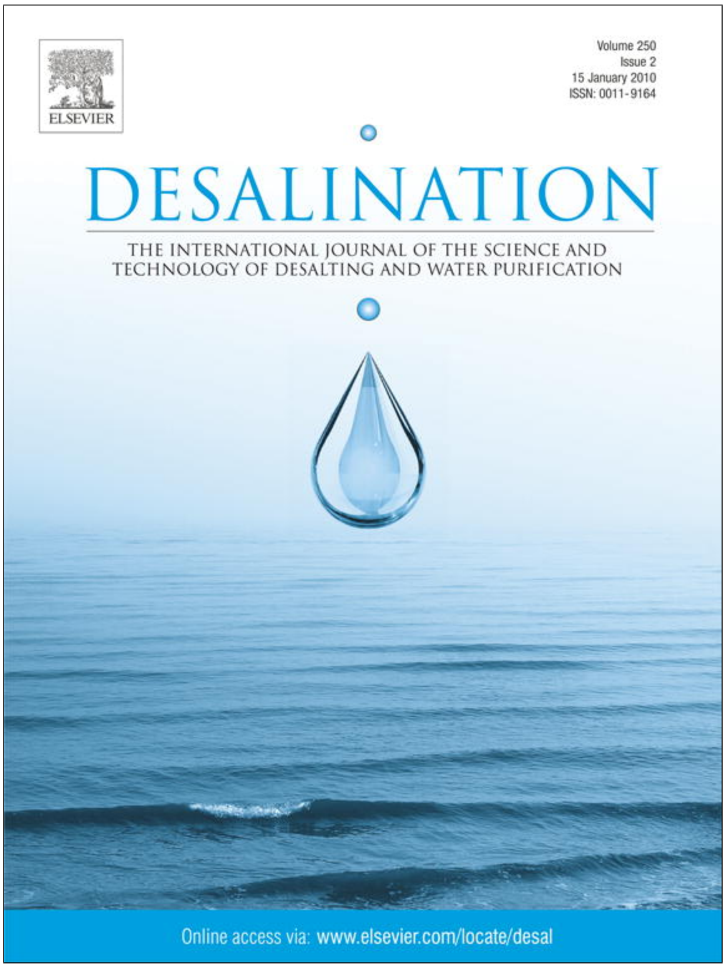

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A new membrane bioreactor generation for wastewater treatment application: Strategy of membrane aeration management by sequencing aeration cycles☆

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ABSTRACT

Polymem is developing in the past few years a new membrane bioreactor concept using external module membranes. The membranes are hollow fibers. They are housed in carters and work in outside/in filtration mode. Permanent air scouring is provided at the bottom of the module to control the accumulation of sludge on the membrane surface. In other words, the membrane carters look like bubble columns with hollow fiber membranes inside.

The main advantages of this concept are the easy maintenance of the external modules; the total independence of the bioreactor from the membrane filtration part, which facilitates plant retrofitting and upgrading; the high membrane compacity (up to 500 m²/m3), and better efficiency of membrane air scouring thanks to a dedicated coarse bubbles aeration system inside the module vessel.

The first part of this paper deals with the quantification of the specific aeration demand of the system. Aeration demand was compared to conventional MBR systems. The study shows that with this optimised geometry of module concept, the aeration flow rate is lowered compared with conventional processes.

In the second part of this paper, an optimisation of the aeration demand was carried out by sequencing the cycle of aeration by incorporating a syncope in the aeration. Ratios of the time-on and time-off from 1/2 to 1/5 were tested for various instantaneous aeration flow rates. Impacts on both short term fouling and long term fouling were evaluated and quantified in terms of permeability decrease. The advantages of the location of the membrane in an external cylindrical carter have been demonstrated in terms of operating cost savings with a reduction of specific aeration demand for membranes scouring at 100 to 250 Nl/h m², which is half the classical consumption of the submerged MBR today.

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1. Introduction

For nearly one century, the concept of coupling between a biological reactor and a settling tank, named activated sludge, has been conventionally used to treat soluble pollutants contained in wastewaters by transforming them in easily settled cell materials. Current limitations of activated sludge are the poor water quality of the settled water which needs tertiary treatment for reuse applications, the extensive footprint of the process and excess sludge production. Since 1970, a new generation of biological treatment has appeared coupling a bioreactor and a membrane filtration instead of the settling tank. By this way, in one step, high quality filtrated water is obtained, footprint is reduced and sludge production is minimised. MBR enables a strict definition of the hydraulic retention time (HRT) and suspended solid retention time (SRT), which gives the opportunity of a better control of the biological reactions and modifies the conditions of selection of the micro-organisms in the aerated tank. The membrane can retain colloids and soluble materials with high molecular weight, improving its biodegradation in the bioreactor. Finally, sludge disposal production is lower than the activated sludge process.

The first MBR generation (1970, still available) is based upon an external tangential filtration over tubular membranes. The high cost of the membranes at this period involved to work at relative high fluxes, 50 to 100 l/h m², to make profitable the installed square meter. High fluxes were maintained only by tangential filtration mode and a high recirculation of the sludges through the membrane cartridges. A tangential filtration process is too expensive (Typically 4 to 6 kWh/m^3) for implementation in a wastewater treatment field and it can explain why the development of the cross flow MBR process was limited to small “niches” like for instance the treatment and reuse of wastewater in the office buildings of large cities like Tokyo.

In the 80's, the developments of both organic membranes and hollow fibers permitted to reduced drastically the cost of the square meter. The innovative paper of K. Yamamoto (1986) was the starting point of a second MBR generation (1990). Today the largest MBR plants installed or projected are able to treat 60 to 80 000 m^3/day which represents about 300,000 inhabitants. In this configuration, the

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membranes are immersed directly in the bioreactor, working in dead-end filtration suction mode. Dead-end filtration instead of crossflow is possible by working at relative small fluxes, 10–20 l/h m² and by increasing the installed membrane surface area. The energy consumption could be decreased to 0.2–0.4 kWh/m^3.

However, maintenance steps of the membranes: integrity tests, chemical cleaning and membrane repairs are very difficult and laborious and constitute an important drawback for the operation of the MBR plants. Furthermore the scouring of the immersed membranes by the small bubbles of the bioprocess aeration was found insufficient to limit the membranes fouling so an extra coarse bubbles aeration system is now required, increasing by the way, the energy consumption of the second generation MBR.

Polymem is pushing a new concept of membrane bioreactor, called Immem, and a new concept of module is proposed which incorporates the advantages of the two previous MBR generations. The driven idea is to have a cost effective dead-end filtration (outside–in like in the second MBR generation) while putting the membranes in dedicated cylindrical module located outside the bioreactor (like in the first MBR generation). This is performed by using dead-end hollow fibers' membranes in an external carter which is fed by a feed pump (Fig. 1). Hydraulic and rejection performance were demonstrated by Lorain et al. [1] in a previous study.

The main advantages of this concept are:

The easy maintenance of the external modules. The risks of human contamination during maintenance and replacement of the membranes are reduced by eliminating the direct contact between workers and the membranes material and handling of closed cartridges is easier than submerged cassette.

The total independence of the bioreactor and the membrane filtration part which facilitates plant retrofitting and upgrading;

The air flow rate for membrane scouring is lower than conventional submerged MBR membranes thanks to an optimised cylindrical vessel around the membrane. By this way, the aeration demand reaches SADm values lower than 300 Nl/h m².

Even if the aeration demand was low compared to conventional MBR, it remains the major energy requirement of our system, around 40% of the operating costs. The objective of this study was to reduce this amount by performing sequenced aeration.

The second idea was to chose the best time to do this aeration cleaning. Van kam et al. [2] have shown that a strong mixing of the sludge, during aeration, involves flocs destruction which increases drastically the viscosity of the activated sludge with EPS releases and so increase the fouling. Our second idea was so to use air scouring only during periods of non-filtration, i.e. backwash of relaxation. During filtration we maintain only a very small bubbling, just to maintain good mixing of the water inside the module.

The study will present the influence of aeration strategy for short and long term experiments. The strategy will be, for the same aeration cycle of 30 s to change the proportion of time for the strong aeration demand and the time of the small aeration demand. Ratios from 1/2 to 1/5 have been tested. Finally in the last trials we have tested to stop strong aeration during the filtration.

Fig. 2. Labège Wastewater Treatment (5 m^3/day).

2. Pilot study

2.1. Material

The pilot plant is located in the wastewater treatment plant of Sicoval Labège (in the suburbs of Toulouse, France) (Figs. 2 and 3).

The pilot is fed with municipal wastewater degrided at 6 mm, desanded and degreased. The principle is presented in Fig. 4.

The wastewater comes from the left of the pilot through a thin screener with 1.5 mm punch holes, to the bioreactor divided into two

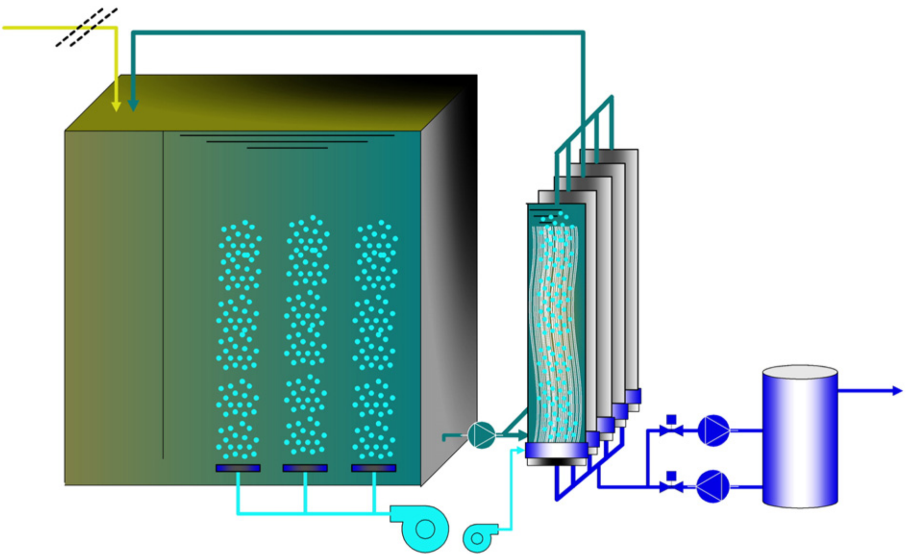

Fig. 1. Immem MBR concept by Polymem where the dead-end filtration modules are located in cylindrical vessels, outside the bioreactor.

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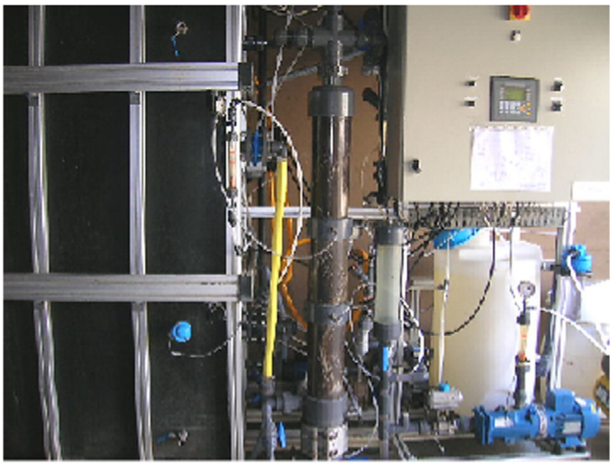

Fig. 3. The pilot plant (5 m^3/day).

parts, an anoxic aera and an aerobic area. The activated sludge is carried to the module via the feed pump. The flow rate entering the module is 400% of treated flow rate Q, so 300% of Q is returned to the bioreactor. This slight renewing allows working at a stabilized concentration of the suspended solids inside the module and returns with a ratio of 300% to the anoxic area.

The module is 1.3 m in length with a carter diameter of 0.135 m. Hollow fibers are potting in one end at the bottom of the module and are free and sealed off at the other end in the top of the module. The fibers are gathered in 4 bundles. Between the bundles, aeration blowers are disposed to provide the coarse bubbles for the scouring of the membranes. A check valve is installed on the module aeration line and controlled by the PLC to sequence the aeration. The module characteristics are summarized in Table 1.

A suction pump is used for the filtration. The permeate goes to the storage tank and the overflow constitutes the production. The permeate storage is used to backwash the membrane thanks to the backwash pump. The pilot was controlled by an automatic device. The operating parameters are listed in the Table 2.

Table 1
Pilot main parameters.

Parameter	Values
Module cross section	0.135 m
Fibers' external diameter	2.5 mm
Number of bundles	4
Filtration surface	7.5 m²
Packing density	403 m^2/m^3
Instantaneous air flow	230 Nl/h m² to 500 Nl/h m²
Gaz velocity Ug	0.046 m/s to 0.1 m/s
Load	0.1 d^{-1}
COD	0.6 g/L
SRT	40 d
HRT	12 h
SS	8–10 g/L

Two levels of aeration flow rates were used: an intensive flow rate for intensive air scouring at 500 Nl/h m² of the membrane and a low flow rate just to maintain well mixing inside the module at 230 Nl/h m². The various sequences tested are presented in Table 3.

3. Results and discussion

3.1. Short term fouling

The evolutions of TMP, for a fixed flux, was followed for various conditions of aeration sequences. In Fig. 5 the cycles were followed during 2 h and superposed in order to estimate the evolution of the TMP during a day. The sequence was 15 s time-on and 15 s time-off giving an average SAD_m of 365 Nl/h m².

All the cycles were the same for 2 h meaning that the system is in steady states. Four aeration sequences were then applied to the system and the TMP evolution was followed during 2 h for each one. Table 3 reminds the aeration sequences conditions.

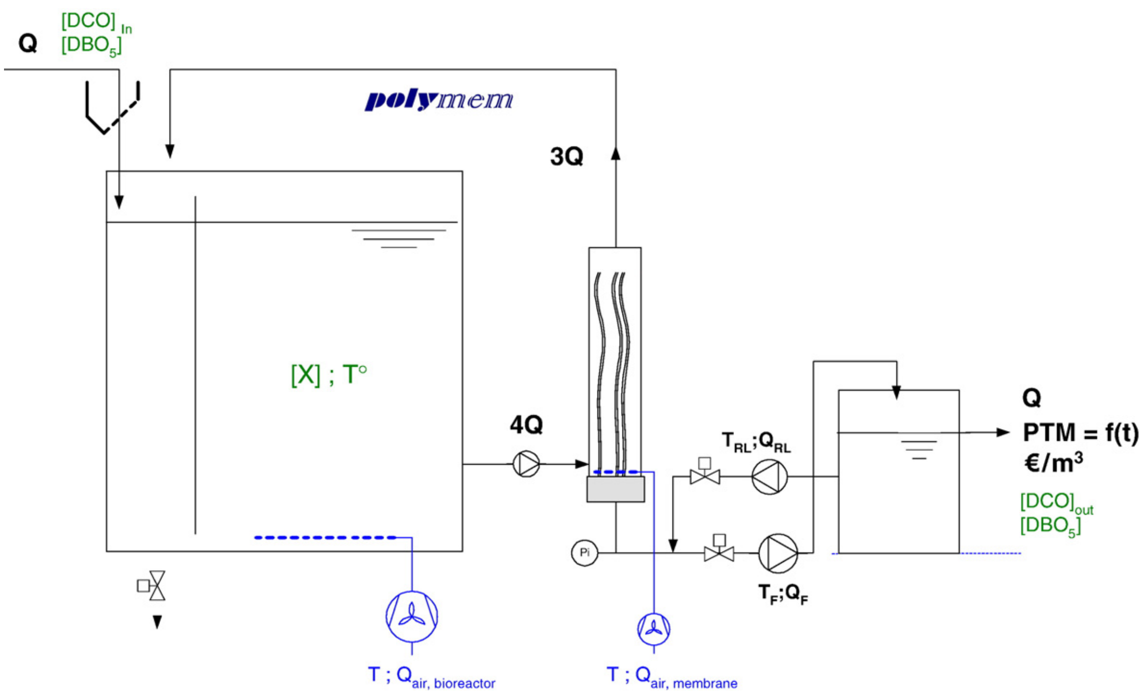

Fig. 4. Immem, MBR pilot PID.

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Table 2
Operating parameters.

Operating parameter	Duration	Flux
Production	300 s	7–8 l/h m²
Backwash	15 s	30 l/h m²
Relaxation period	30 s	0 L h m²

Table 3
Aeration sequences.

Sequence number	Duration of high flow/low flow	Average SADm (Nl/h m²)
1	30 s/0 s	500
2	15 s/15 s	365
3	10 s/20 s	320
4	5 s/25 s	275

Fig. 6 shows the evolution of TMP for the four conditions.

The evolutions of TMP for the four various conditions of aeration are the same for short term fouling. No TMP increase is noticed after four hours running for any sequences tested. At short term, increase of aeration flow seems not to improve the limitation of membrane fouling.

3.2. Long term filtration

The reduction of aeration seems to have no impact on short term fouling. Long term experiments were then carried out to determine if tendencies are the same. The strategy of aeration is described in Table 4.

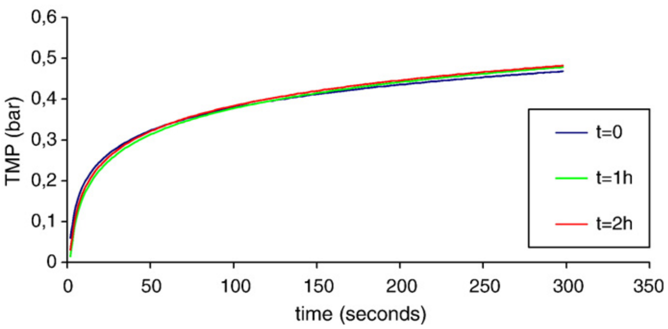

Fig. 5. TMP evolution for the same sequence during 2 h.

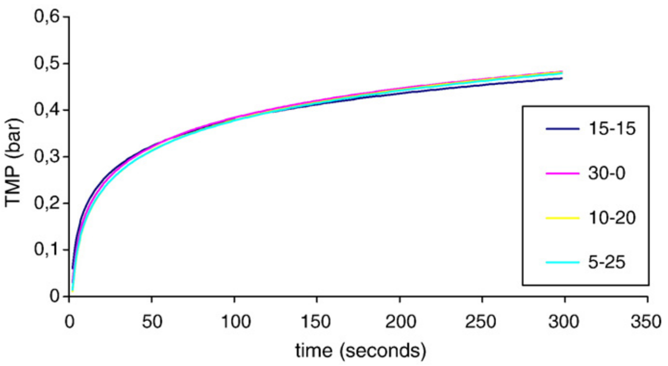

Fig. 6. TMP evolution for various sequences of aeration.

Table 4
Aeration sequences.

Sequence number	Aeration sequences			Average SADm (Nl/h m²)
	Filtration	Backwash	Relaxation	
1	15 s on–15 s off	15 s on–15 s off	15 s on–15 s off	350
2	5 s on–25 s off	5 s on–25 s off	5 s on–25 s off	260
3	Only low flow	Only high flow	Only low flow	190

Three various conditions were tested at least one week each:

A classical condition of 15 s time-on and 15 s time-off;
A condition with an important reduction of the time of intensive aeration, 5 s time-on and 25 s time-off;
In the last trial, a particular strategy was used by applying the low aeration during filtration period and strong intensive aeration only during backwash. The idea being to avoid destruction of the flocs during the more critical step which is the filtration.

Fig. 7 shows the evolution of permeability, Lp, compared with the permeability at the beginning of the run Lp° through the time for the 3 aeration sequences.

With the first sequence, the membrane permeability decreases to 40% in four days. We cleaned the membrane chemically and restarted the run with the sequence number two and we limit the time of intensive aeration at 5 s per 30 s i.e. 1/6 of the total time. The loose of permeability compared to the previous run was lower. Vankaam and Albasi [2] have shown that a high stress of the sludge involves releases of cellular materials of the bacteria which make the interstitial liquid more difficult to filtrate. In our experiment we finally reduce the time of bacteria stressing and it can explain the relative facility of biomass to be filtrated when it is less stressed.

Following these evolutions, we decided to go on lowering the hydraulic perturbation of the biomass and chose an original strategy of aeration:

Low aeration during filtration step to keep the flocs intact, limit the release of cellular substances in the interstitial liquid and to reduce the fouling tendencies of the slurry.
High aeration only during the period of backwash of the membrane. It represents the best time to scour the membrane because the cake deposit is lifted-up and tends to be removed from the surface with backflush.

With this last number 3 sequence, the evolution of permeability is the same than for sequence number 2 but the average value of aeration was lowered again and reached a value of 190 Nl/h m². A high aeration of only 15 s of a whole cycle of 5 min seems to be sufficient to keep the same conditions for the permeability decrease, but it seems to be important to do it during the backwash steps. Further experiments are in progress to check this hypothesis.

4. Conclusions

Membrane aeration is a key point for MBR operation however the choice of aeration strategy is empirical. Sequenced aeration is advantageous to reduce the energy consumption. In this study we have shown that:

- The optimised geometry of the external dead-end module concept could be permitted to work with a very low aeration flow rate of 350 Nl/h m² which is much lower than the conventional MBR process.
- Optimisation of aeration by sequencing can reduce the aeration demand to 260 Nl/h m².

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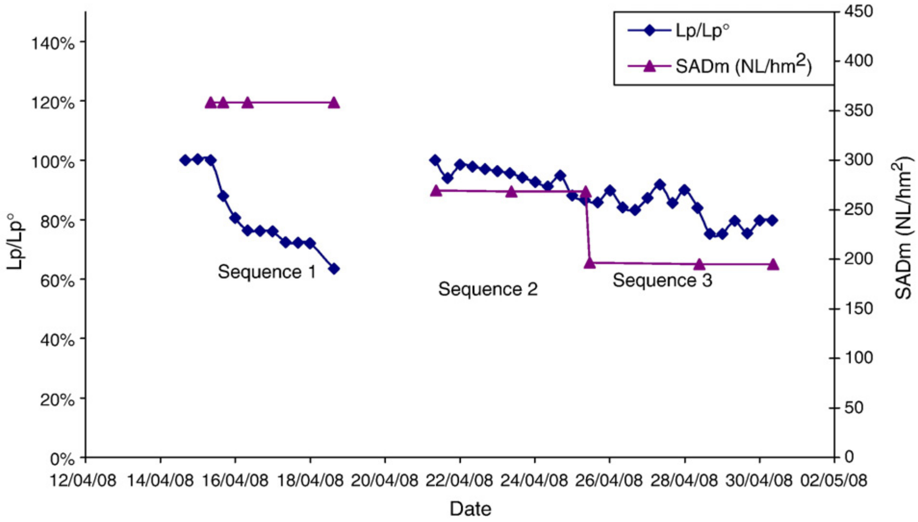

Fig. 7. Long term fouling for different aeration sequences.

- The strategy of low aeration during filtration and high aeration during backwash has shown good results to control membrane fouling and reduce the aeration demand to 190 Nl/h m².

Further experiments are in progress to confirm these first tendencies. The hypothesis which has to be confirmed is that the biomass has less fouling tendencies when it is less stressed (low aeration during filtration) even if we work above the critical flux.

Acknowledgements

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