Artículo de investigación/ Research paper

Design and operational issues of 7 full-scale MBRs for municipal wastewater treatment

Diagnosis del diseño y operación de 7 BRMs municipales para el tratamiento de aguas residuales

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Recibido: 26 de mayo de 2015

Aceptado 20 de junio de 2015

Abstract

Membrane bioreactors (MBRs) represent an emerging technology for the advanced secondary treatment of municipal wastewater around the world. In this line, seven municipal MBRs facilities recently built, with capacities ranging from 1,100 $m^3 \cdot day^{-1}$ to 35,000 $m^3 \cdot day^{-1}$ (up to 100,000 $m^3 \cdot day^{-1}$ in total) have been diagnosed. The evaluation of the design and operational issues revealed significant improvements from the oldest to the newest MBR installed. The main operational issues surveyed have been classified and described in three different categories: i) design limitations, (ii) membranes and equipment failure and (iii) operational problems, with inter-relationships between them. The two oldest MBRs showed broken membranes after six and seven years of operation, respectively, being required its replacement. While foaming has been determined as the most common operational problem, other troubles such as clogging, reduction of denitrification process efficiency or the air in the permeate line were of more concern for the practitioners. Moreover, fouling has not been mentioned by any of the practitioners and energy consumption has been determined as the main limitation of this technology.

Keywords: MBRs, membranes, wastewater, operational issues, design parameters

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Resumen

Los bioreactors de membranas (BRMs) representan una tecnología emergente por el tratamiento de aguas residuales alrededor del mundo. En esta línea, siete BRMs municipales recientemente construidas, con capacidades entre 1,100 $m^3 \cdot día^{-1}$ to 35,000 $m^3 \cdot dí^{a-1}$(hasta 100,000 $m^3 \cdot día^{-1}$ en total) han sido diagnosticadas. La evaluación del diseño y operación a través de encuestas ha sido clasificada y descrita en tres categorías distintas: i) limitaciones de diseño, ii) fallos en el equipamiento y en las membranas y iii) problemas operacionales, con sus pertinentes interrelaciones entre ellos. Los dos BRMs más antiguos presentaron membranas rotas seis y siete años de operaciones, respectivamente, siendo necesario su reemplazamiento. Mientras que las espumas (foaming) han sido identificadas como mayor problema de operación en común, otros problemas como el taponamiento (clogging), la reducción del proceso de desnitrificación o el aire en las líneas de permeado han sido los que más preocupan a sus explotadores. Además, el ensuciamiento no ha sido mencionado en ninguna de las encuestas y el consumo energético identificado como la mayor limitación de dicha tecnología.

Palabras clave: BRMs, membranas, agua residuals, problemas operacionales, paràmetros de diseño

1. Introduction

Prior to the onset global financial crisis, the market for membrane bioreactors (MBRs) had been growing at a rate of ~11% [1], with municipal wastewater treatment applications apparently making up 44% of all the systems installed [2]. It is widely acknowledged that MBRs offer the key advantages of smaller footprint and a very high effluent quality, with microorganism and solids removal in particular, compared the conventional activated sludge process (CAS) [3].

However, MBRs are costly and more complex in design and operation than CAS plants, mainly due to the fouling phenomenon, demanding regular maintenance to maintain membrane cleanliness [3]. Specifically, Le-Clech [4] reviewed the MBR operational issues, determining as the main limitations: Pre-treatment and clogging, fouling and fouling control, aeration and oxygen transfer, membrane integrity and expected lifetime and energy consumption and cost consideration. Afterwards, Santos et al. [5] surveyed to membrane product suppliers, technology suppliers, end users, and consultants *what was the main technical problem that prevents MBRs working as they should?* The problems identified in this study were: screening and pre-treatment (22%), membrane and aerator clogging (19%), hydraulic overloading or system under design (17%), membrane fouling or fouling resistance (15%), Automation or control (9%), membrane cleaning (6%), sludge quality (5%), energy (3%), operator knowledge (2%) and uneven aeration (2%). It is possible to find relationships between the listed topics, concluding that the aggregate percentage value of the number of responses pertaining to fouling, cleaning and overloading is 38%, less than the aggregate value for clogging and screening (41%). According to these studies, although membrane fouling captures most attention accounting for around 31% of all MBR papers published [5], there are much bigger concerns for MBR users [4,5,6].

Focusing on the full-scale municipal MBRs recently commissioned, seven facilities were updated with this technology between 2003 and 2010 in Catalonia (Spain). This region is located in the Mediterranean zone, characterized by seasonal and regional water scarcity imposed by weather conditions and tourism. These factors have driven MBR implementation aimed at (i) conserving freshwater resources through indirect water reuse (e.g. aquifer recharge through river bed infiltration), (ii) improving of effluent quality for discharge to accomplish the stricter legislations, and (iii) increasing plants capacity with physical space limitations through retrofitting of membrane technology.

It is of interest to both the academic and practitioner communities to review the status of MBR technology. To this end, an examination of the seven full-scale MBRs located in Catalonia has been conducted. Together with the understanding of the full-scale MBRs design and operation, there has been a particular interest in the MBR operational problems, in order to find the bigger concerns for municipal MBR practitioners.

2. Full-scale MBR surveyed

Data collection

Seven facilities were surveyed from 2009 to 2012. Information for the survey was acquired from:

a) The regional governmental authority, providing design and construction data
b) Plant operators, from whom key design, and operation and maintenance (O&M) data was captured through (i) completion of written question-

naires, and (ii) face-to-face interviews conducted during site visits, and (iii) follow up communications by telephone and/or email.

General characteristics

The surveyed MBR installations are the result of the refurbishment of existing plants due to the need to increase the capacity of the facilities with physical space limitations (table 1). The seven plants can be divided into the following categories:

- three stand-alone MBRs (A, B, C);
- one "hybrid" process (D), where the existing oxidation ditch has been retrofitted with an aerated buffer tank and a membrane filtration tank while maintaining the secondary settler to treat peak flows and wet weather conditions;
- one "dual-stream" WWTP (E) with two complete parallel treatment lines: MBR and conventional activated sludge treatment, where the MBR treats 30% of the influent flow and the remaining influent flow is treated by a conventional activated sludge system followed by secondary settlers;
- two "dual-stream" WWTPs with two complete parallel treatment lines: MBR and integrated fixed-film activated sludge (IFAS) (F – Dispersed Media IFAS Systems, G – Fixed Media IFAS Systems). The MBRs treat 40% and 15% of the influent, respectively, and the remainder of the flow is treated by the IFAS technology line followed by secondary settlers.

All of the plants were designed for nutrient (nitrogen and phosphorous) removal, with the exception of plant B. The membrane technologies used in the plants are GE Zenon hollow fibre (HF), used in five of the facilities, and Kubota flat sheet (FS), installed in two of the facilities.

TABLE 1. MBR PLANTS, GENERAL INFORMATION. (HF: HOLLOW FIBRE; FS: FLAT SHEET)

WWTP	Year of commissioning	WWTP Design capacity (m^3 day^{-1})	MBR design capacity (m^3 day^{-1})	Type of membranes	Primary settler or buffer tank
A –MBR	2004	2,160	2,160	FS	No
B –MBR	2009	1,100	1,100	HF	No
C –MBR	2010	1,320	1,320	HF	No
D – hybrid MBR-CAS*	2003	6,225	3,225	HF	Yes
E – dual-stream MBR-CAS*	2008	65,000	35,000	FS	Yes
F – dual-stream MBR-IFAS**	2009	64,000	32,000	HF	Yes
G – dual-stream MBR-IFAS**	2009	90,000	15,000	HF	Yes

*CAS: Conventional activated sludge process
** Integrated fixed-film activated sludge process

3. WWTP design and operational data review

Design and operational data of MBR pre-treatment and operation were reviewed.

3.1. Pre-treatment

MBRs demand adequate pre-treatment to prevent fats, oils and grease and gross solids [3], including fibrous material, from entering the membrane compartment where they can cause problems of "ragging" [7]. All the plants surveyed employ a coarse screen (mesh size 12-800 mm) and a micro-sieve (0.5-3 mm), with the latter installed specifically to protect the membrane. Most of the facilities have grit chambers and an extra fine screen (1 - 6 mm), with three having a buffer tank. Whilst the ameliorative effects of primary sedimentation on MBR energy demand have been demonstrated [8], footprint and/or cost constraints have meant that only three of the surveyed facilities (B, E and F) have primary settlement installed, with two of these (E and F) having now bypassed this stage.

It is evident that the most recent of the installations studied have the most rigorous pre-treatment (Fig. 1). The oldest plant (D) was originally fitted with a 1 mm split screen and was upgraded with a 1 mm round-hole screen two years after the MBR start-up (Figure 1) to reduce the entrance of fibres content to the MBR compartment. The range of fine mesh sizes observed (0.5 - 3 mm) is in general agreement with those reported in other surveys [9,10], though there appears to be pattern of round-hole screen configuration for six of the seven WWTPs. Otherwise, as it was expected, there is a less rigorous screening for the FS membrane modules [3,9].

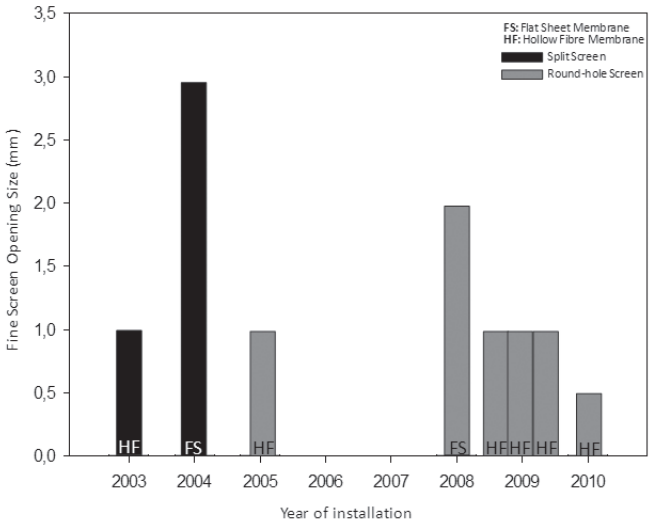

FIGURE 1.–Fine screen sizes installed and typologies of membranes used after each fine screen.

3.2. Membrane filtration

Operation of the five HF MBRs (Table 2) is characterised by "cyclic aeration", a proprietary membrane air scouring mode which reduces the membrane aeration demand by dividing the air flow between adjacent lanes [11]. Cycling is normally based on a 10 s cycle, i.e. 10 seconds "on" and 10 seconds "off", although for D-HF-MBR the period is 6s. More recently a "10/30" cycle has been introduced for non-peak flow periods where the membrane is scoured for 10 seconds with 30s between air scours, halving the aeration rate over that of 10/10 aeration. Filtration cycles of 10 minutes with 30-40 seconds of backwashing are used in most cases, with the exception of two plants. At D-HF-MBR a small dose of sodium hypochlorite (NaClO) is added in each backwash cycle to create a "chemically-enhanced backwash" (CEB), and at B-HF-MBR alternate permeate/backwash and permeate/relaxation cycles are programmed due to the low operational flux (flow per unit membrane area) employed.

TABLE 2. MBR DESIGN AND OPERATIONAL PARAMETERS.

PARAMETER	A	B	C	D	E	F	G
Design flux [L m^{-2} h^{-1}]	21	18	18	23	24	25	27
Model	Kubota EK 400	ZeeWeed 500d	ZeeWeed 500d	ZeeWeed 500c	Kubota EK 400	ZeeWeed 500d	ZeeWeed 500d
Number of Modules	14	80	96	264	192	1,848	720
Membrane area [m^2]	4,410	2,526	3,030	5,808	61,440	58,400	22,752
SAD_m[mh^{-1}]	0.65	0.31	0.31	0.37	0.53	0.33	0.31
Design SA-D_p[mh^{-1}]	31.9	17.5	17.09	15.9	22.1	14.4	11.4
Permeate cycles	9' F 1' R	10' P 30"BW 10' P 30"R	10' P 30"BW	10' P 40"BW (NaClO)	9' P 1' R	10' P 30"BW	10' P 30"BW
Maintenance chemical cleaning (BWP or BWG)	(BWG) TMP < -0.3 bars NaClO 5.000 mg/L	(BWP) Weekly NaClO 100 mg/L	(BWP) Weekly NaClO 200 mg/L	(BWP) TMP < -0.4 bars NaClO 100 mg/L EDTA 200 mg/L	(BWG) TMP < -0.2 bars NaClO 5.000 mg/L	BWP) Weekly NaClO 200 mg/L	(BWP) Weekly NaClO 200 mg/L
Recovery chemical cleaning (IR)	--	Twice a year NaClO or $C_6H_8O_7$	Twice a year NaClO or $C_6H_8O_7$	Twice a year NaClO or $C_6H_8O_7$	--	Twice a year NaClO $C_6H_8O_7$	Twice a year NaClO or $C_6H_8O_7$
Visual inspection	Not planned	Not planned	Not planned	Every 2-3 months	Not planned		

*SAD_m: Specific aeration demand per membrane surface
**SAD_p: Specific aeration demand per permeate flow
F: filtration, BW: backwashing, R:relaxation
BWP: chemical reagents are black-flown using the back-wash pump inside the membrane reactor
BWG= chemical reagents are back-flown under gravity inside the membrane
IR: chemicals reagents are added inside the membrane reactor (full)

The specific aeration demand per unit of membrane area (SAD_m) is similar among the HF plants at 0.3-0.4 $m·h^{-1}$ but significantly lower than the values for the FS plants (0.5-0.6 $m·h^{-1}$), as expected from known trends [3]. Likewise, the specific aeration demand per unit of cubic meter of design permeate (SADp) is similar among the HF facilities, being the lower values related to the biggest facilities (F and G).

Weekly chemical cleaning of the HF plants takes place using a dilute (100 $mg.L^{-1}$) NaClO solution with occasional use of citric acid, when the NaClO was not efficient enough to recover the permeability values. One plant also employs EDTA for maintenance cleaning to prevent the formation of precipitate, originated by the reaction between NaClO and divalent ions Calcium and Magnesium due to the hardness of the influent wastewater treated. The recovery chemical cleaning of the HF is carried out twice a year. The sludge is evacuated and the membranes soaked in a solution with NaClO (1,000 - 1,500 $mg·L^{-1}$) and citric acid (2,000 $mg·L^{-1}$) for 6-12 hours. In FS plants maintenance cleanings are carried out with a gravity-driven backwash of the chemical cleaning reagent when the TMP is lower than -0.2 or -0.3 bars for E and A, respectively.

3.3. Costs

Operational costs have been reported by the practitioners as the main disadvantage of this technology. Table 3 shows the energy consumption values for the entire full-scale facilities, including all of the plant units (pre-treatment, biological process, MBR and sludge treatment). It was not possible to determine the costs only related to the MBR process, mainly because the WWTPs did not have a separate electricity meter for this unit.

Energy consumption values for the stand-alone facilities (A, B and C) were higher than the values presented by the hybrid and dual-stream plants (D, E, F and G). Focusing on the stand-alone MBRs, high ranges of energy consumption were observed, being possible to associate the lowest consumption values to the highest hydraulic loads. All the values presented are in agreement with recently published values [3, 12, 13], except for the facility C. This facility was temporarily operating via on-site generation and the recalculated values from diesel consumption ratios are disproportionally higher than the expected ones.

4. MBR Problems

The MBR problems identified by the practitioners were classified into three different subgroups, with inter-relationships between some of these: (i) Design limitations, (ii) membranes and equipment failure and (iii) operating problems.

TABLE 3. ENERGY CONSUMPTION BEFORE AND AFTER MBR INSTALLATION IN THE FACILITY

Facility	Consumption (2011-2012(kW·h/m³))		
	Average ratio	Max	Min
A	0.7	0.92	0.51
B	1.16	0.77	1.53
C	7.27*	12.88*	3.76*
D	0.67	0.95	0.39
E	0.85	0.97	0.73
F	0.55	0.63	0.45
G	0.46	0.53	0.37

*Energy consumption values were converted from diesel consumption

4.1. Design limitations

Several design limitations were recognized by the practitioners. These limitations affected the correct operation of the MBR systems and generated operational problems described in the next sections. Specifically, the main limitations identified are listed below:

- Physical space limitation to realize the visual inspection or reparation of membranes.
- Lack of sensors and instrumentation to monitor the process.
- Inefficient foaming trapping systems: all the MBRs experience foaming episodes that deteriorate the operation and were not
- SCADA and software systems.
- Sludge dewatering systems: MBR sludge properties are different than CAS.

- The Uncovered biological tanks: allows the entrance of foreign bodies that can damage the membrane (described in section *membrane integrity*).

Most of these design limitation could be avoided if the facility was completely adapted to the MBR technology' requirements when MBR was installed, instead of maintaining the old treatment units.

4.2. Membranes and equipment failure

Membrane integrity

In the oldest WWTPs (A-FS-MBR and D-hybrid MBR-CAS), broken membranes were found after some years of operation. Taking into account the existent classification of the four main causes of membrane damaging (Chemical oxidation, faulty installation, presence of foreign bodies and faulty membrane/model structure) defined by Le-Clech et al. [4], it is possible to define the observed failures as:

- A-FS-MBR: **Presence of foreign bodies**. The membranes tank is uncovered making easy the entrance of leafs and other external bodies. After six years of operation, a visual inspection revealed that a 15% of the membranes were broken. All the broken membranes were replaced by new ones.
- D-hybrid MBR-CAS: **Faulty module structure**. Specifically, the bottom structure of the membrane cassette was broken, which provoked the bursting of its membranes and the surrounding ones. It was necessary to replace some of these membranes and seal the others. Specifically, after 6 years of operation, 15 membranes elements were replaced (5.6 % of the total surface), 4 elements were completely manually cleaned and 16 were partially sealed, losing a 0.3% of the total filtration surface.

Mechanical failures

Mechanical problems are related to the damage of the instrumentation and equipment, including sensors (F and G HF-MBRs) or valves, pumps and air compressors (A-FS-MBR, B and D-HF-MBRs), mainly when they are in contact with the chemicals used to clean the membranes, such as corrosion of pipes by chloride (A-FS-MBR and D-HF-MBR).

4.3. Operational problems

Most of the operational problems appear as a consequence of the design limitations or mechanical breakdowns. Specifically, the main operational troubles surveyed : 7/7 foaming, 3/7 clogging, 3/7 Nitrogen removal, 3/7 membrane cleaning 3/7 air presence in the permeate line.

Despite the fouling phenomenon is the most studied topic about MBRs, fouling episodes were not reported or identified as a problem in any of the facilities. It could be due to the high number of chemical cleanings that are usually carried in the 7 MBR surveyed. These results are in line with the conclusion of other studies where the clogging and screening issues are more frequent than fouling and cleanings ones [5].

Foaming

Foaming episodes were the most common operating problem identified (7/7 facilities). Specifically, all the full-scale MBRs experienced a yearly foaming episode. It is widely known that the operational conditions of an MBR plant promote foam development as a result of high MLSS concentration in the aeration tank, high SRT and low F/M ratio [14, 15]. However, different types of foaming were recognized in the surveyed facilities: chemical and biological foaming. Unlike the detergent-type white foam commonly observed in treatment plants, almost all recent foaming problems are associated with a biological foam that is more viscous and stable than chemical foam [16]. This behaviour was observed in the studied facilities, where six out of the seven plants WWTPs suffered biological foaming episodes, while only one facility reported the high surfactants entrance as the origin this phenomenon (Table 4).

Full-scale plant operators' routine uses the SVI the measurement to monitor the floc structure of sludge, together with punctual activated sludge microscope observations. Reported SVI values showed a yearly variation, being possible to observe the higher values during the coldest months. It is due to the temperature effects on the sludge properties and more concretely, on the bacteria population. Specifically, *M.parvicella,* the most common filamentous bacteria identified, is associated with low temperatures conditions [17].

TABLE 4.- FOAMING INFORMATION OF EACH FULL-SCALE MBR

Plant	Typology	Main filamentous or cause	SVI (ml·g⁻¹)		Solutions applied
			December - May	June-November	
A	Biological	Type 0041*	--	--	modifying the mixed liquor suspended solids concentration
B	Biological	*M.parvicella*	130 ± 14	107 ± 15	aluminium polychloride (PAX) addition
C	Biological	-	208 ± 24	142 ± 24	---
D	Biological	*M.parvicella* and type 0041*	406 ± 30	179 ± 31	aluminium polychloride (PAX) addition
E	Biological	---	319 ± 42	239 ± 41	---
F	Biological	*M.parvicella*	82 ± 10	75 ± 14	adding sprays at the bioreactor surface and/or in the recycle channel aluminium polychloride (PAX) addition
G	Chemical	Industrial discharges (tensioactives)	197 ± 76	77 ± 11	adding sprays at the bioreactor surface and/or in the recycle channel

--INFORMATION NOT available. * Filamentous more associated to bulking than foaming.

These episodes were faced with specific methods (modifying the main operating parameters of the biological process, such as the sludge retention time, the loading rate, the dissolved oxygen concentration, etc.) or non-specific methods (adding chemicals) [18]. Specifically, the A-MBR solved this problem by modifying the mixed liquor suspended solids concentration. Likewise, when a moderate foaming presence is observed, F and G-MBRs control the foaming by adding sprats at the bioreactor surface and/or in the recycle channel. However, when this specific method is not enough, foaming is solved by adding aluminium polychloride (PAX) as in the other two facilities, B and D-MBRs. Nevertheless, as other studies reported [10] if stable brown foam becomes established at an installation its mitigation is very challenging. It happened in the facility E, where a reliable solution for foaming mitigation has not been identified yet.

Clogging phenomenon

Clogging episodes were identified in three out of the seven MBRs studied, specifically in the oldest ones. Specifically, clogging arises when agglomeration of solids takes place within or at the entrance to the membrane channels, affecting the permeability of the filtration process [3]. Clogging can be categorised as 'sludging' or 'ragging'. Sludging refers to the filling of membrane channels with sludge solids and depends on process design (membrane module and aerator, pre-treatment), flux and flux distribution, and membrane aeration distribution [19, 20]. Ragging (or 'braiding') is the term used to define the blocking of membrane channels with particles agglomerated. In the evaluated full-scale MBR different clogging typologies were identified, as it described below:

- A-FS-MBR. This FS facility operated for more than one year at MLSS concentrations higher than 20 $g \cdot L^{-1}$. These conditions favored the sludge deposition on the membranes surface, generating sludging phenomenon . Moreover, the membrane tanks are located close to pine trees, which leafs, can lead easily inside the tank and helped the formation of the clogs.
- Once identified the problem, the MLSS concentration was decreased in order to avoid the sludge accumulation on the membranes surface. Since then, the leaf entrance is only affecting the membranes integrity, but not increasing the sludging phenomenon.
- B-HF-MBR: Despite the fact that this facility has an exhaustive pre-treatment, the entrance of foreign bodies to the membranes tank caused the clog of the top of the HF membranes. Specifically, the biological tank, that is partly uncovered, is located close to deciduous trees which generates a high entrance of leafs to the tank. After one year of operation it was necessary to remove the cassettes and clean them manually in order to remove the clogs based on leafs and sludge deposition from the top of the membranes surface. It is required to completely cover the biological tanks in order to avoid further clogging problems.
- D-HF-MBR: the typology of clogging detected was ragging phenomenon [7], because it was due to an unsatisfactory pre-treatment that permits the pass of textile fibres and other similar structures. This phenomenon generated severe filtration problems [21].

Nitrogen removal

Aeration is used both to provide oxygen for maintaining in suspension the MLSS, and to control fouling by scouring on the membrane surface [3, 22]. Consequently, dissolve oxygen (DO) concentration in this compartment reaches values higher than 4 $mg \cdot L^{-1}$ [23]. It would negatively impact the nitrogen removal efficiency of the MBR system, especially when this high DO concentration is transferred to the head of the process in a high mixed liquor recycle flow typically employed for denitrification. This high DO concentration would deteriorate the required anoxic conditions for denitrifying bacteria, which are facultative bacteria that energetically prefer oxygen versus nitrate as the terminal electron acceptor [24]. This reduction of the denitrification efficiency has been reported by three full-scale MBRs (B, C and G). Specifically, G facility implemented a control system to recycle the sludge from the membranes compartment to the anoxic or aerobic tank, depending on the dissolved oxygen concentration of the activated sludge. This system ensures the low DO conditions of the anoxic tank and consequently, the efficiency of the denitrification process.

Air in the permeate pipes

The presence of air in the permeate pipes has been considered a trouble in three out of the seven plants. Despite that air is expected to be found in the permeate line on an MBR, it is only considered a problem if it affects the filtration performance. Specifically, facilities B and D experimented start-up problems after the recovery cleanings, due to the high entrance of air in the permeate line. An extra vacuum system was required to purge the air present in the permeate line and avoid the start-up problems. Likewise, the under-suction permeate extraction of the FS-MBR (A) generated a high amount of air in the permeate line, causing the permeate pump damage.

MBR maintenance

Difficulties to guarantee the conditions described by the manufacturers for the chemical cleanings methodologies were identified in three out of the seven plants. The FS-MBR (A) does not have an automatic system to conduct the chemical cleaning, making it very difficult to ensure the correct distribution of the chemical reagent through the membrane panels. On the other hand, the HF-MBRs A and B, presented difficulties to achieve the high NaClO concentration required for the recovery cleanings. They also experienced problems to start-up the operation after carry out the chemical cleanings.

Moreover, all the plant managers complained about the fast degradability of the chemical reagents used (i.e. NaClO), which made it difficult to guarantee that the chemical concentration used for the cleaning was exactly the mount required.

5. Conclusions

An exhaustive evaluation of the MBR design and operation has been conducted in order to provide the state-of-the-art of this technology in Catalonia. Significant improvements on the MBR design (i.e. the pre-treatment and membrane configurations) have been observed from the first to the last MBR installed in Catalonia. Regarding the pre-treatment, an increase of attention has been observed. Newest facilities preferred round-hole geometry with small hole-size for the sieves. Similarly, the HF cassettes have been improved, being possible to use cyclic aeration systems to reduce the air-scour required for the membranes cleaning.

The main operational issues surveyed have been classified in three different categories: i) design limitations, (ii) membranes and equipment failure and (iii) operational problems, with inter-relationships between them. The two oldest MBRs showed broken membranes after six years of operation, being required its replacement. Foaming and clogging have been determined as the worst operational problems, while fouling has not been mentioned by any of the practitioners. It could be related to the conservative way of operation of the HF-MBRS, based on applying a minimum of a weekly maintenance cleaning.

Finally, all the practitioners surveyed concluded that the main drawback of this technology is the energy consumption associated to the MBR unit, showing the necessity to find feasible optimisation strategies to minimise the operational costs of this technology.

6. Acknowledgements

This research was funded by the Catalan Water Agency (ACA) and the Ministry of Science and Innovation (waterfate).The authors would like to thank the staff of the WWTPs of La Bisbal d'Empordà, Riells i Viabrea, Vallvidrera, Gavà-Viladecans, Sabadell-Riu Sec, Terrassa and Vacarisses, and the companies ITT Flygt, Telwesa and HERA AMASA.

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